US009242122B2

(12) **United States Patent**
Tsoref et al.

(10) **Patent No.: US 9,242,122 B2**
(45) **Date of Patent: Jan. 26, 2016**

(54) **REFLECTANCE-FACILITATED ULTRASOUND TREATMENT AND MONITORING**

(76) Inventors: **Liat Tsoref**, Tel Aviv (IL); **Yossi Gross**, Moshav Mazor (IL); **Michael Kardosh**, Kiryat Ono (IL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 420 days.

(21) Appl. No.: **13/697,831**

(22) PCT Filed: **May 12, 2011**

(86) PCT No.: **PCT/IL2011/000382**
§ 371 (c)(1),
(2), (4) Date: **Jan. 9, 2013**

(87) PCT Pub. No.: **WO2011/141918**
PCT Pub. Date: **Nov. 17, 2011**

(65) **Prior Publication Data**

US 2013/0103028 A1 Apr. 25, 2013

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/780,240, filed on May 14, 2010, now Pat. No. 8,617,150, and a continuation-in-part of application No. 13/015,951, filed on Jan. 28, 2011, now Pat. No. 8,956,346.

(51) **Int. Cl.**
A61B 18/14 (2006.01)
A61N 7/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .. ***A61N 7/02*** (2013.01); ***A61N 7/00*** (2013.01); ***A61N 7/022*** (2013.01); *A61B 18/1492* (2013.01); *A61B 2017/00084* (2013.01); *A61B 2017/00106* (2013.01); *A61B 2017/00247* (2013.01); *A61B 2017/00256* (2013.01); *A61B 2018/00285* (2013.01); *A61B 2018/0212* (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,619,247 A 10/1986 Inoue et al.
5,676,692 A * 10/1997 Sanghvi et al. 606/27
(Continued)

FOREIGN PATENT DOCUMENTS

WO 99/40957 A1 8/1999
WO 03/097162 A2 11/2003
(Continued)

OTHER PUBLICATIONS

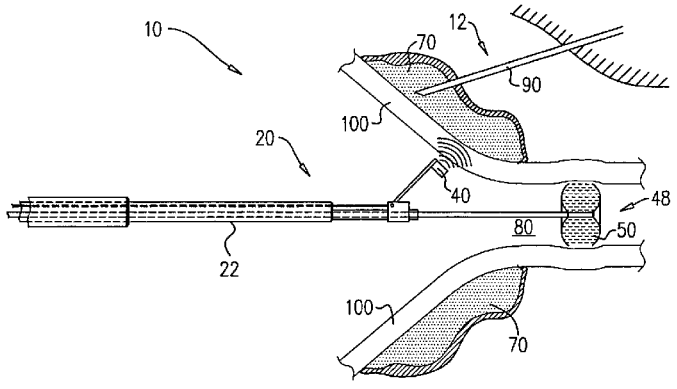
International Search Report and Written Opinion dated Aug. 12, 2013 PCT/IL13/50134.
(Continued)

Primary Examiner — Michael Peffley
(74) *Attorney, Agent, or Firm* — Ladas & Parry LLP

(57) **ABSTRACT**

Apparatus comprising an ultrasound ablation system (**10**), which comprises a reflection-facilitation element (**12**), configured to be placed at an extramyocardial site of a subject, and to provide an extramyocardial reflective region; and an ultra-sound tool (**20**), which comprises at least one ultrasound transducer (**40**) configured to be positioned within a heart chamber of the subject. The ultrasound transducer (**40**) is configured to ablate myocardial tissue by applying ultrasound energy to the myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue. Other embodiments are also described.

8 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

A61N 7/00	(2006.01)
A61B 17/00	(2006.01)
A61B 18/00	(2006.01)
A61B 18/02	(2006.01)
A61B 19/00	(2006.01)

(52) **U.S. Cl.**

CPC ... *A61B2019/4054* (2013.01); *A61N 2007/003* (2013.01); *A61N 2007/0021* (2013.01); *A61N 2007/0043* (2013.01); *A61N 2007/0065* (2013.01); *A61N 2007/0069* (2013.01); *A61N 2007/0078* (2013.01); *A61N 2007/0091* (2013.01); *A61N 2007/027* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,735,280	A	4/1998	Sherman et al.	
5,776,063	A	7/1998	Dittrich et al.	
5,817,022	A	10/1998	Vesely	
5,827,216	A	10/1998	Igo et al.	
6,004,269	A	12/1999	Crowley et al.	
6,050,943	A	4/2000	Slayton et al.	
6,064,902	A	5/2000	Haissaguerre et al.	
6,083,166	A	7/2000	Holdaway et al.	
6,128,523	A	10/2000	Bechtold et al.	
6,216,704	B1	4/2001	Ingle et al.	
6,241,727	B1	6/2001	Tu et al.	
6,425,877	B1	7/2002	Edwards	
6,575,969	B1	6/2003	Rittman et al.	
6,605,084	B2	8/2003	Acker et al.	
6,635,054	B2 *	10/2003	Fjield et al.	606/27
6,641,579	B1	11/2003	Bernardi et al.	
6,659,950	B2	12/2003	Taheri	
6,672,312	B2 *	1/2004	Acker	128/898
6,685,639	B1	2/2004	Wang et al.	
6,701,931	B2	3/2004	Sliwa, Jr. et al.	
6,805,129	B1	10/2004	Pless et al.	
7,022,105	B1	4/2006	Edwards	
7,037,306	B2	5/2006	Podany et al.	
7,226,440	B2	6/2007	Gelfand et al.	
7,311,701	B2	12/2007	Gifford et al.	
7,326,201	B2	2/2008	Fjield et al.	
7,565,191	B2	7/2009	Burbank et al.	
7,662,099	B2	2/2010	Podany et al.	
8,197,409	B2	6/2012	Foley et al.	
2001/0003798	A1	6/2001	McGovern et al.	
2002/0091427	A1	7/2002	Rappaport et al.	
2003/0018256	A1	1/2003	Sasaki et al.	
2004/0034339	A1	2/2004	Stoller et al.	
2004/0097788	A1	5/2004	Mourlas et al.	
2004/0162507	A1	8/2004	Govari	
2004/0162550	A1	8/2004	Govari et al.	
2005/0020921	A1	1/2005	Glassell et al.	
2005/0080469	A1	4/2005	Larson et al.	
2005/0165298	A1	7/2005	Larson et al.	
2005/0203410	A1	9/2005	Jenkins	
2005/0251125	A1	11/2005	Pless et al.	
2006/0009753	A1	1/2006	Fjield et al.	
2006/0058711	A1	3/2006	Harhen et al.	
2006/0079868	A1	4/2006	Makin et al.	
2006/0100514	A1	5/2006	Lopath	
2006/0184048	A1	8/2006	Saadat	
2006/0241523	A1	10/2006	Sinelnikov et al.	
2007/0004984	A1 *	1/2007	Crum et al.	600/471
2007/0093420	A1	4/2007	Yeomans et al.	
2007/0239077	A1	10/2007	Azhari et al.	
2007/0265610	A1	11/2007	Thapliyal et al.	
2008/0015445	A1	1/2008	Saadat et al.	
2008/0033415	A1	2/2008	Rieker et al.	
2008/0058682	A1	3/2008	Azhari et al.	
2008/0091109	A1	4/2008	Abraham	
2009/0048514	A1	2/2009	Azhari et al.	
2009/0062790	A1	3/2009	Malchano et al.	
2009/0137900	A1	5/2009	Bonner et al.	
2009/0192506	A9	7/2009	Vaska et al.	
2009/0247912	A1	10/2009	Warnking	
2009/0326511	A1	12/2009	Shivkumar	
2010/0036292	A1	2/2010	Darlington et al.	
2010/0130836	A1	5/2010	Malchano et al.	
2010/0168624	A1	7/2010	Sliwa	
2011/0178541	A1	7/2011	Azhari	
2011/0184322	A1	7/2011	Brawer et al.	
2011/0251524	A1	10/2011	Azhari et al.	
2011/0282203	A1	11/2011	Tsoref et al.	
2011/0282249	A1	11/2011	Tsoref et al.	
2012/0130363	A1	5/2012	Kim et al.	
2012/0296240	A1	11/2012	Azhari et al.	

FOREIGN PATENT DOCUMENTS

WO	2006/072928	A2	7/2006
WO	2007/134258	A2	11/2007
WO	2011/141918	A2	11/2011
WO	2012/120495	A2	9/2012

OTHER PUBLICATIONS

Non-Final Office Action, dated May 8, 2014, for U.S. Appl. No. 13/015,951.

USPTO NFOA dated May 17, 2013 in connection with U.S. Appl. No. 12/780,240.

Eric Buch, MD, et al; "Intra-Pericardial Balloon Retraction of the Left Atrium: A Novel Method to Prevent Esophageal Injury During Catheter Ablation", Heart Rhythm, Oct. 2008; vol. 5, Issue 10, pp. 1473-1475.

David Cassak, et al; "Endosense: Facing Technology and Financing Challenges in AF", In-Vivo: The Business & Medicine Report, Mar. 2010, pp. 36-44.

William E. Cohn, MD, et al; "Contrast Pericardiography Facilitates Intrapericardial Navigation Under Fluoroscopy", An. Thorac Surg; vol. 90, pp. 1537-1540 Accepted for publication Jun. 7, 2010.

Luigi Di Biase, MD, et al; "Prevention of phrenic nerve injury during epicardial ablation: Comparison of methods for separating the phrenic nerve from the epicardial surface", Heart Rhythm; Epub Mar. 19, 2009; vol. 6, Issue 7, pp. 957-961.

Srijoy Muhapatra, MD, et al; "Pressure frequency characteristics of the pericardial space and thorax during subxiphoid access for epicardial ventricular tachycardia ablation", Heart Rhythm; Epub Jan. 15, 2010; vol. 7, Issue 5, pp. 604-609.

Seiichiro Matsuo, MD et al; "Novel Technique to Prevent Left Phrenic Nerve Injury During Epicardial Catheter Ablation", Circulation, Jun. 3, 2008, vol. 117, Issue 22, 2 pages.

Shiro Nakahara, MD, et al; "Intrapericardial balloon placement for prevention of collateral injury during catheter ablation of the left atrium in a porcine model", Heart Rhythm, Epub Sep. 17, 2009; vol. 7, Issue 1, pp. 81-87.

Frederic Sacher, MD et al; "Phrenic Nerve Injury After Catheter Ablation of Atrial Fibrillation", Indian Pacing Electrophysiology Journal, vol. 7, Issue 1, pp. 1-6; Published online Jan. 1, 2007.

Richard B. Schuessler, PhD et al; "Animal studies of epicardial atrial ablation", Heart Rhythm, Dec. 2009; vol. 6, 12 Suppl. pp. S41-S45.

Jeanne Shen, BS et al; "The surgical treatment of atrial fibrillation", Heart Rhythm, vol. 6, No. 8S, August Supplement 2009, 7 pages.

S. Tanaka et al; "Development of a New Vascular Endoscopic System for Observing Inner Wall of Aorta Using Intermittent Saline Jet", World Congress on Medical Physics and Biomedical Engineering, Sep. 7-12, 2009, Munich, Germany, 8 pages.

Guillermo J. Tearney, MD, PhD et al; "Three-Dimensional Coronary Artery Microscopy by Intracoronary Optical Frequency Domain Imaging", JAAC Cardiovasc Imaging, Nov. 2008; vol. 1, Issue 6, pp. 752-761.

International Search Report dated Jul. 31, 2008; PCT/US07/68818.

International Search Report and Written Opinion dated Oct. 26, 2011 PCT/IL11/00382.

International Preliminary Report on Patentability dated Nov. 20, 2012; PCT/IL2011/000382.

International Search Report and Written Opinion dated Sep. 17, 2012; PCT/IL2012/000100.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO NFOA mailed Dec. 20, 2012 in connection with U.S. Appl. No. 11/653,115.

USPTO NFOA dated Feb. 19, 2013 in connection with U.S. Appl. No. 13/010,555.

USPTO RR dated Feb. 25, 2013 in connection with U.S. Appl. No. 12/780,240.

* cited by examiner

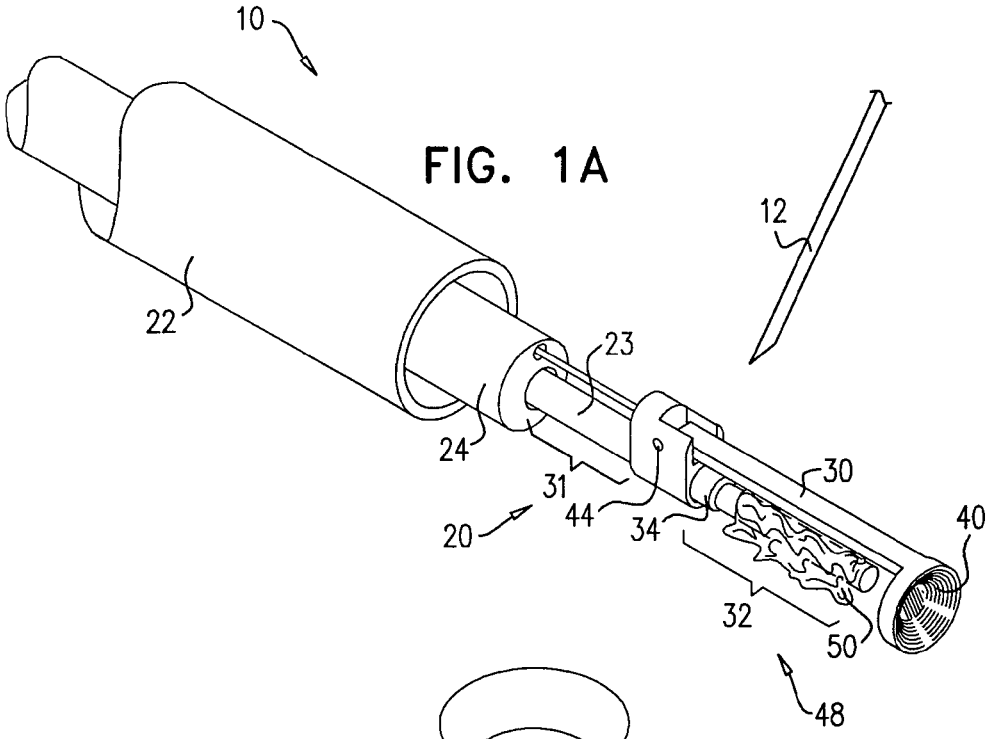

10
12
22
23
24
31
44
34
30
40
20
32
50
48

FIG. 1A

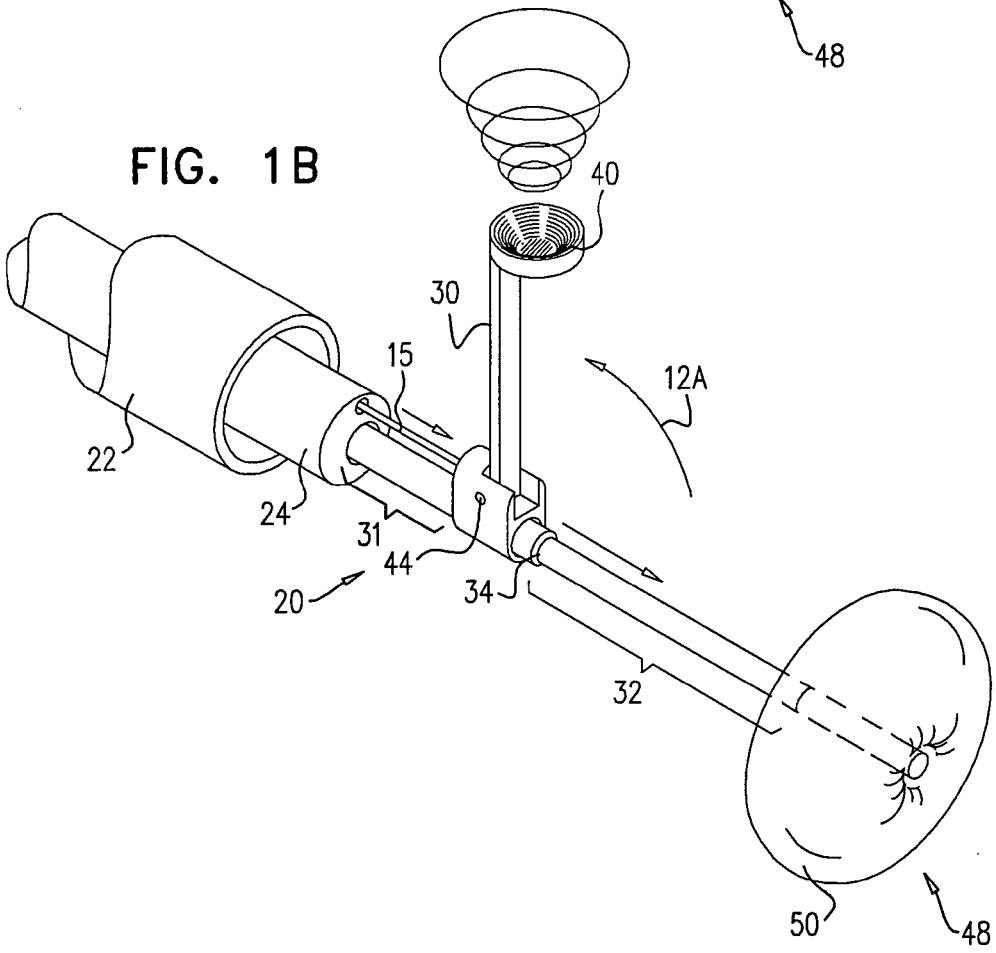

40
30
15
12A
22
24
31
44
20
34
32
50
48

FIG. 1B

FIG. 2A

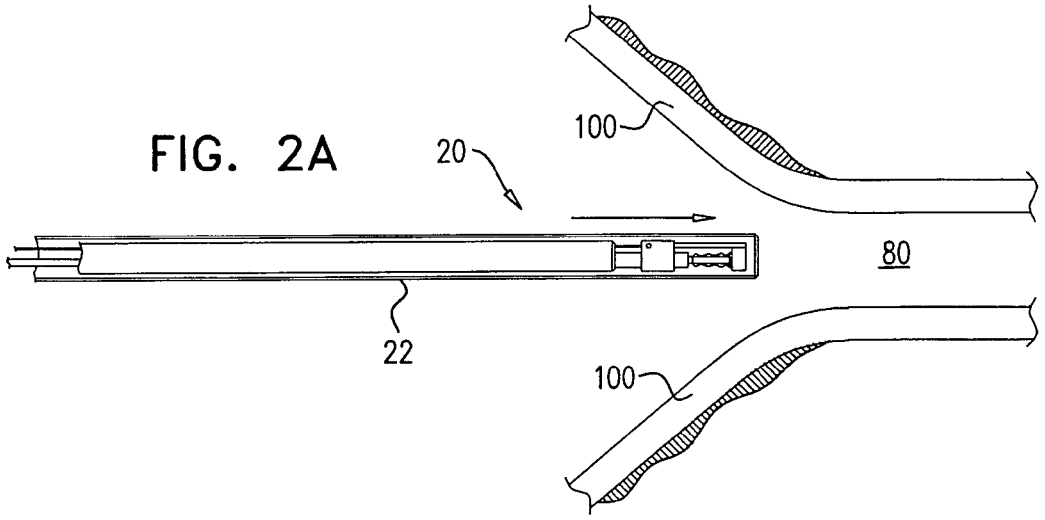


FIG. 2B

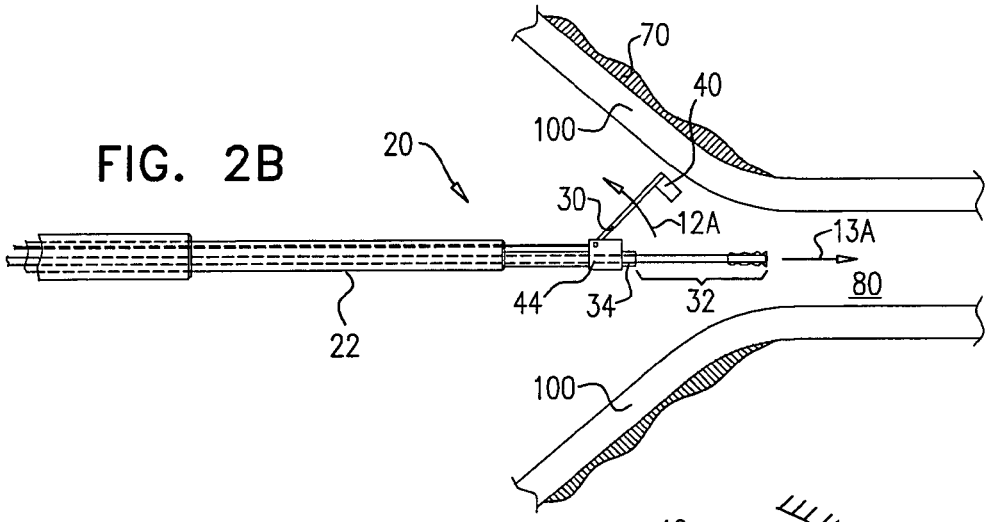
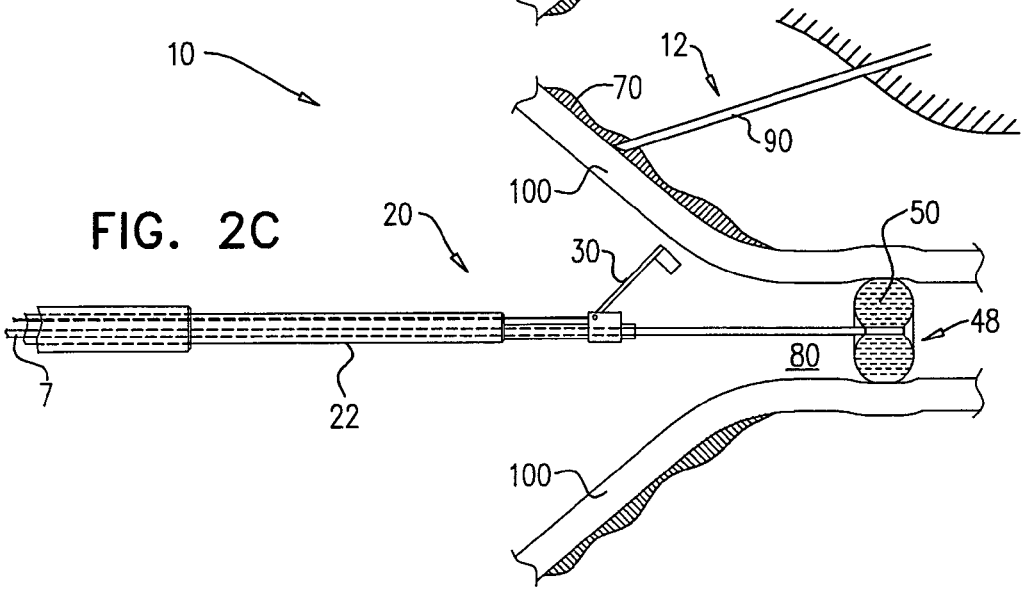


FIG. 2C



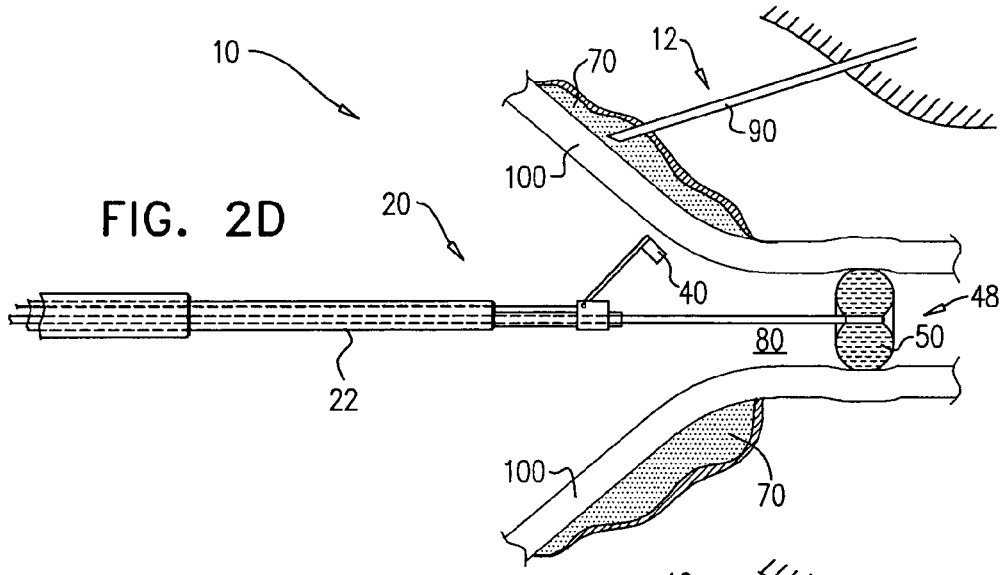


FIG. 2D

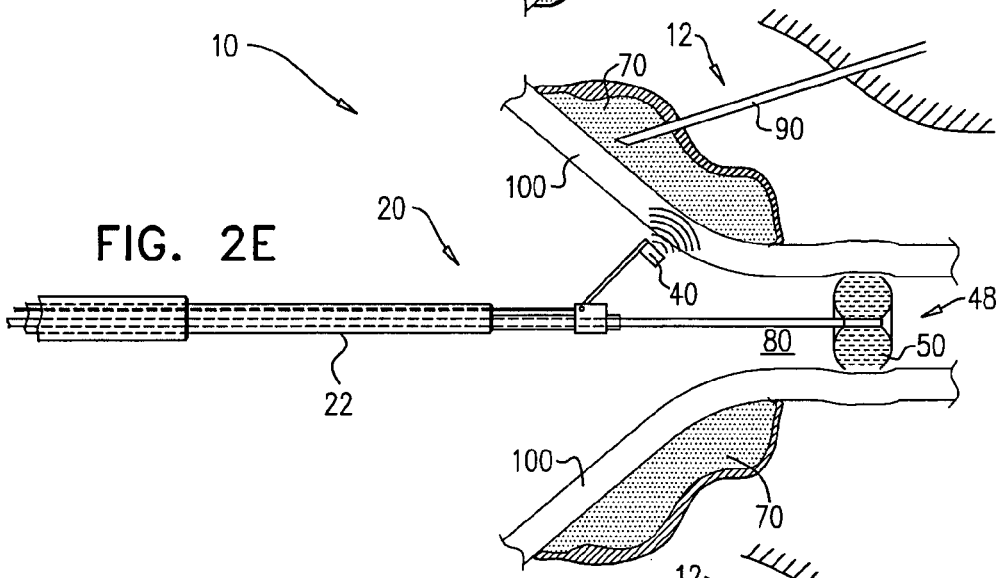


FIG. 2E

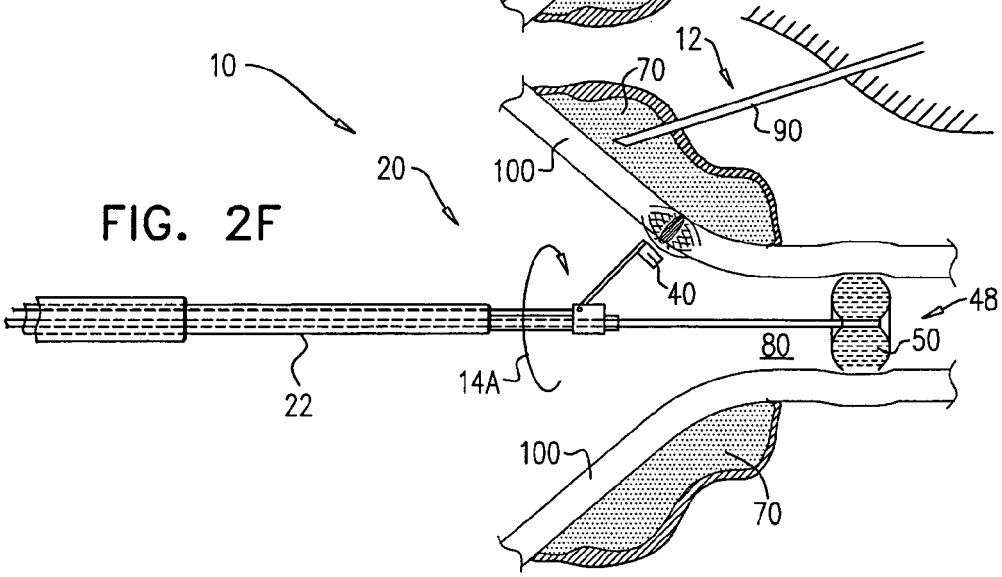


FIG. 2F

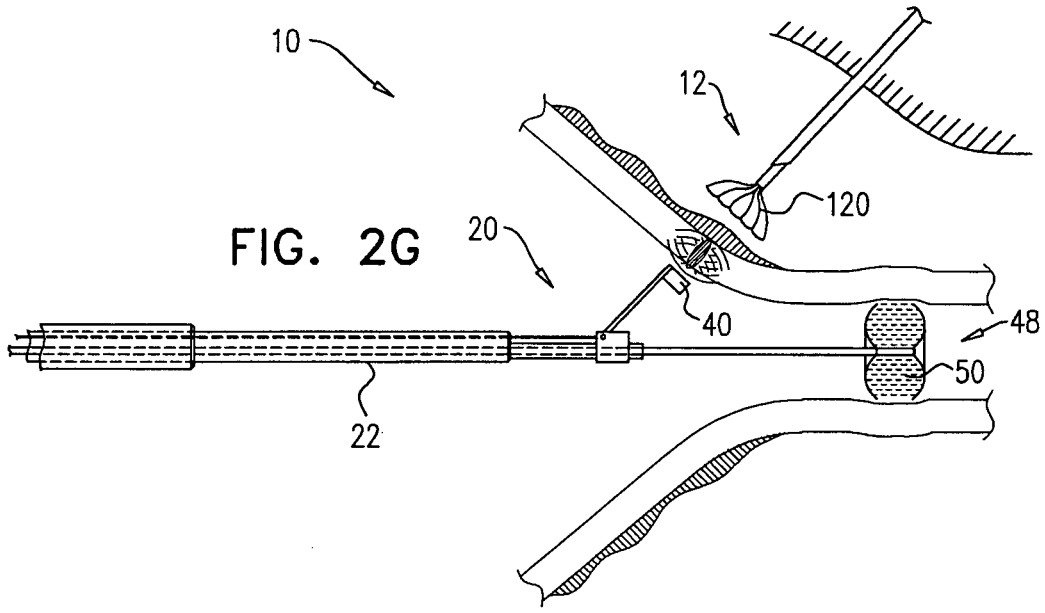


FIG. 2G

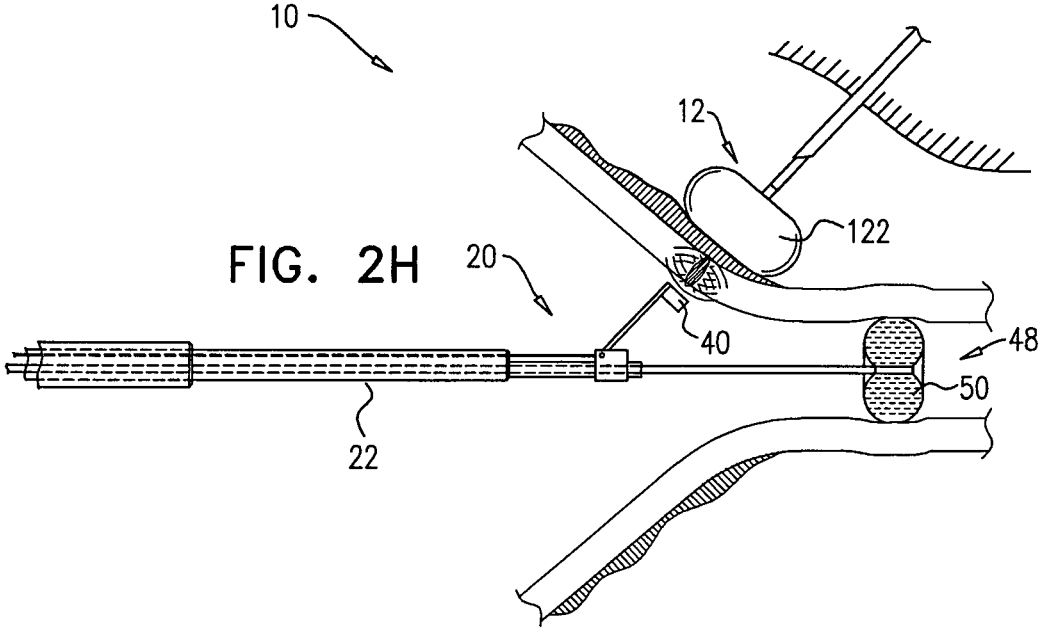


FIG. 2H

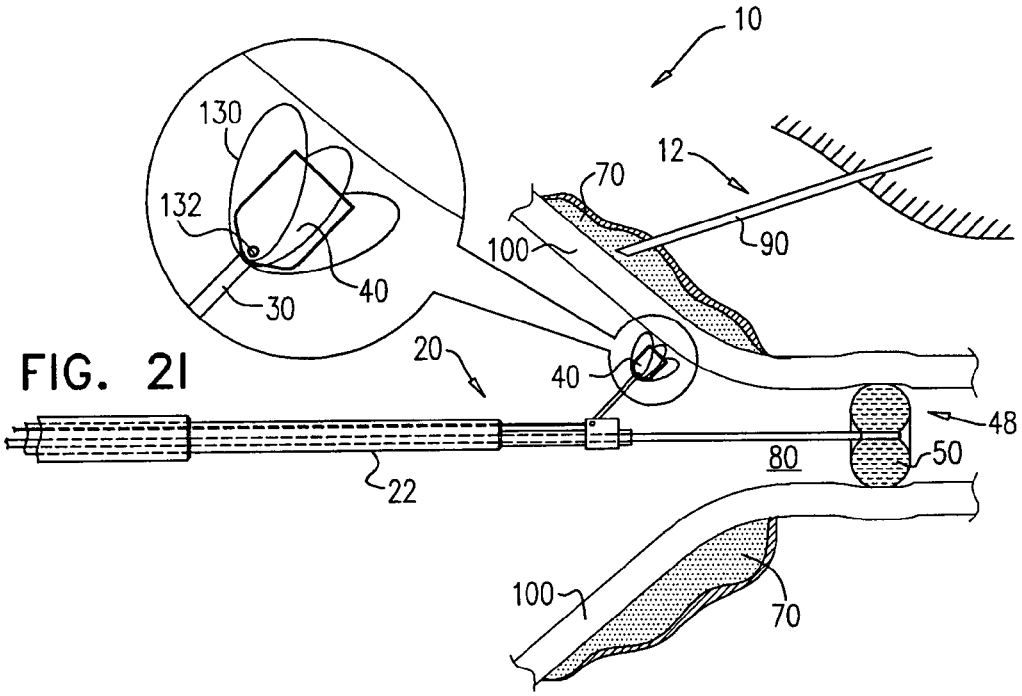

10
130
132
40
30
12
70
90
100
20
40
48
80
50
22
100
70

FIG. 2I

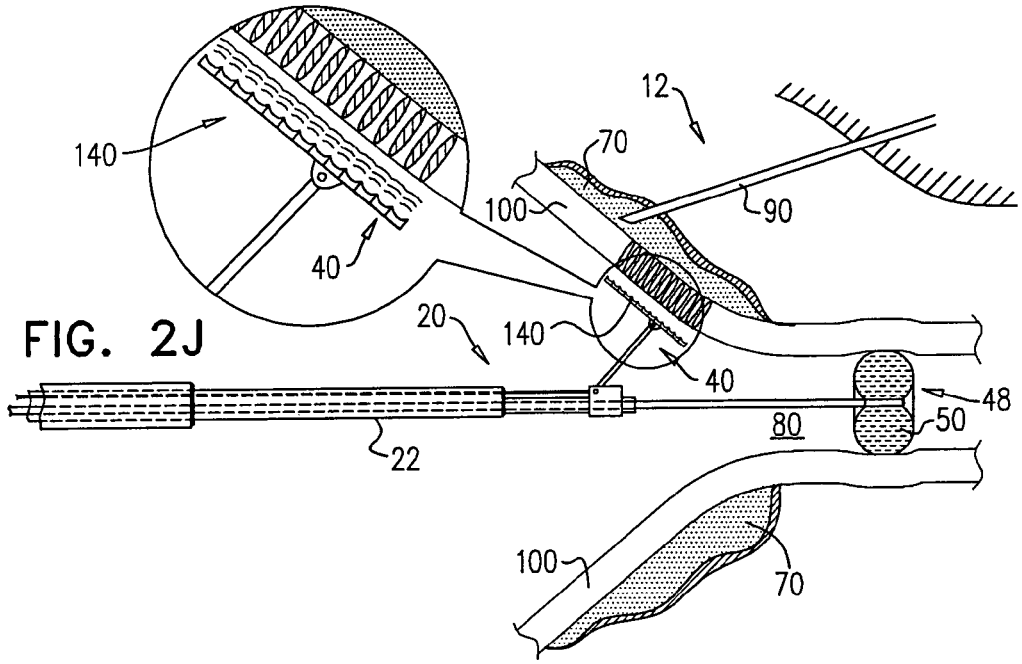

140
40
12
70
90
100
20
140
40
48
80
50
22
100
70

FIG. 2J

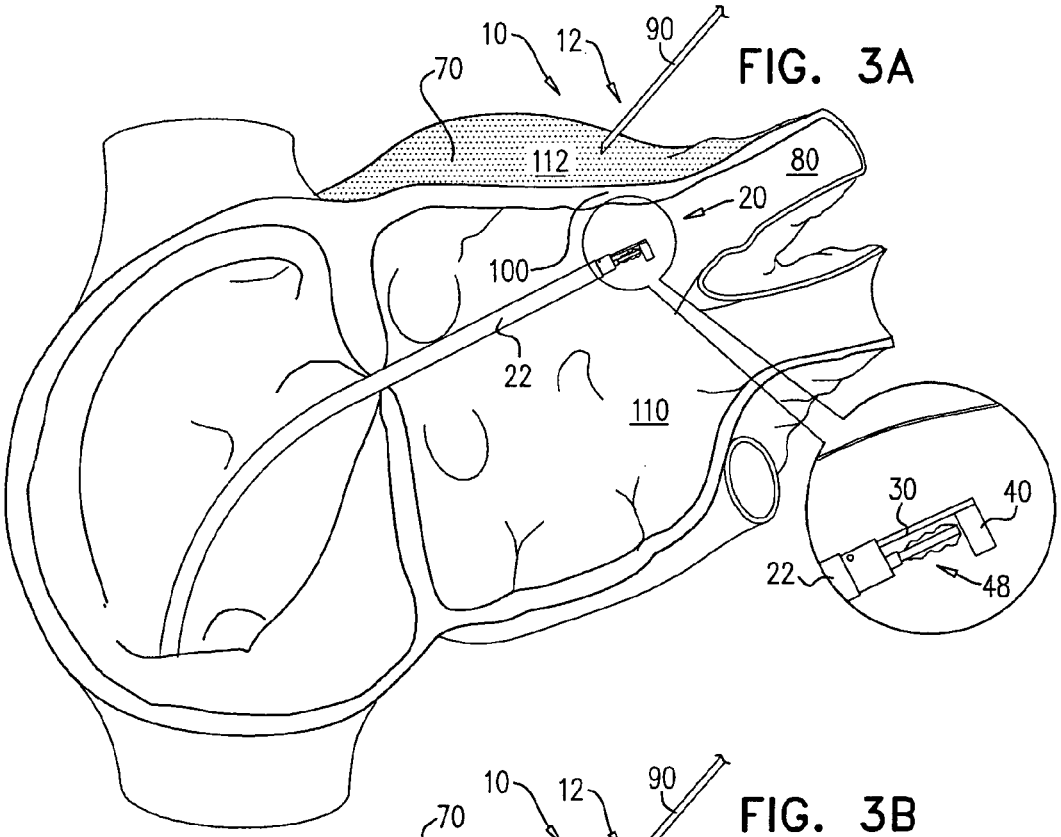

10
12
90
70
112
80
20
100
22
110
30
40
22
48

FIG. 3A

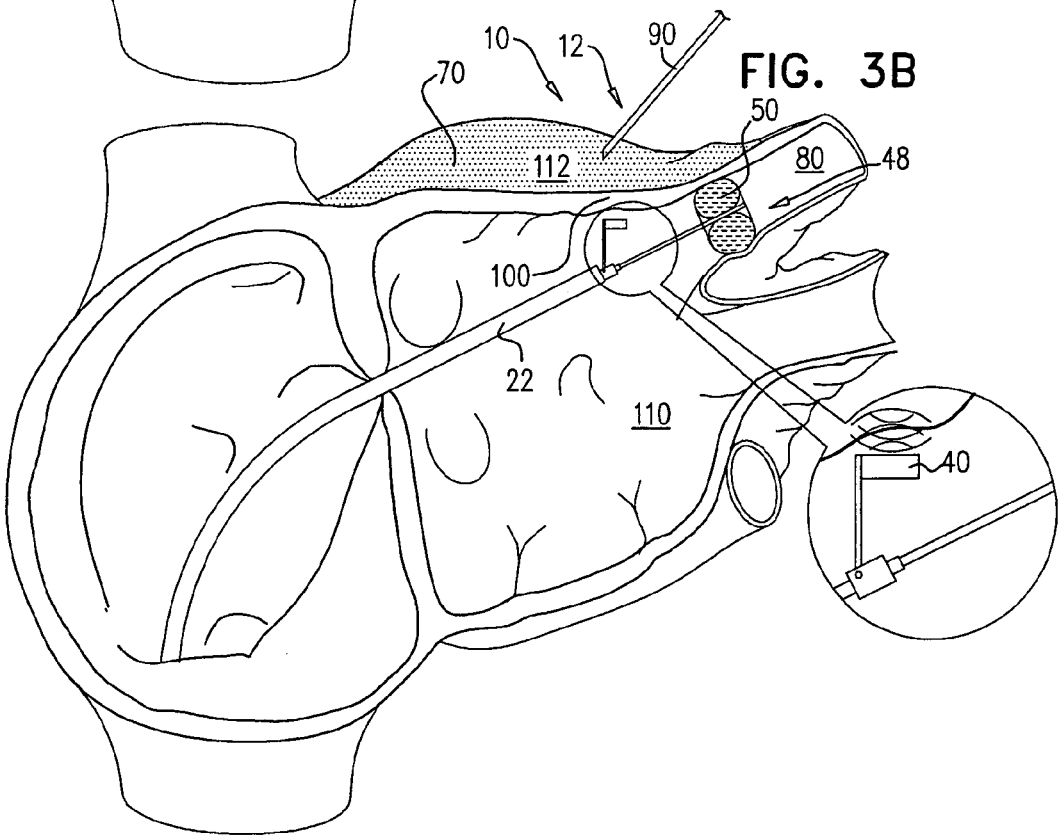

10
12
90
70
50
112
80
48
100
22
110
40

FIG. 3B

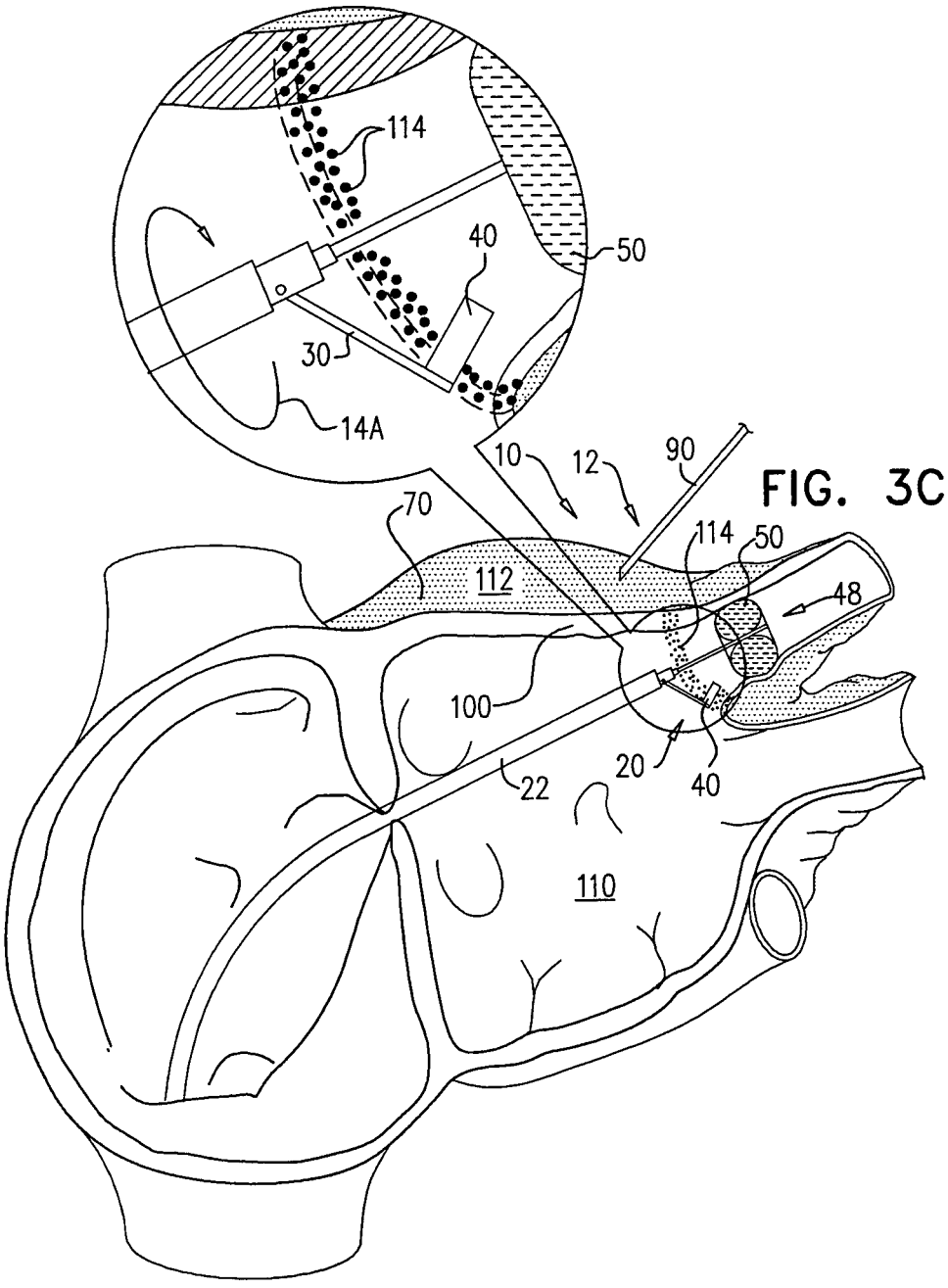


FIG. 3C

FIG. 4A

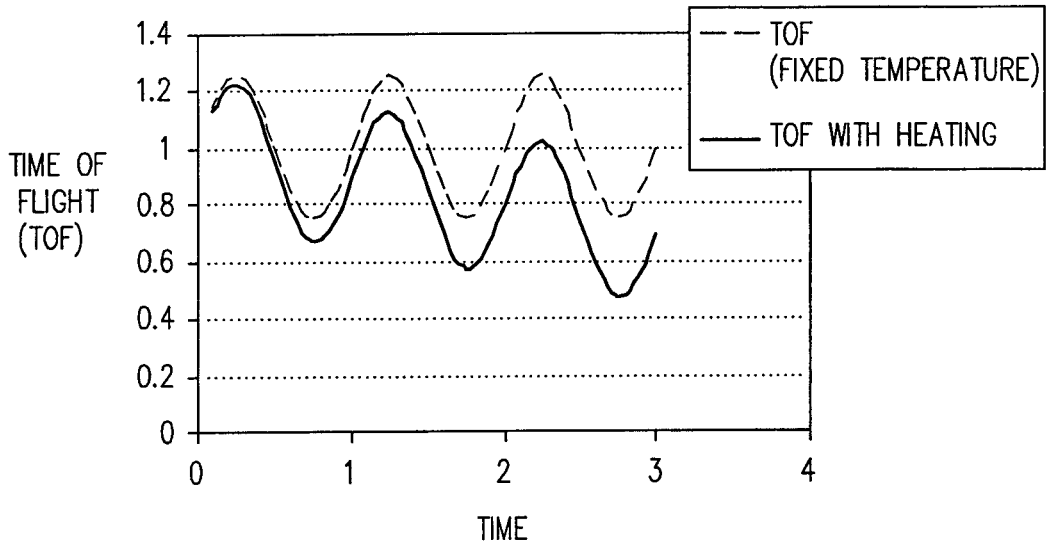

TOF
(FIXED TEMPERATURE)
TOF WITH HEATING
TIME OF FLIGHT (TOF)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
TIME

FIG. 4B

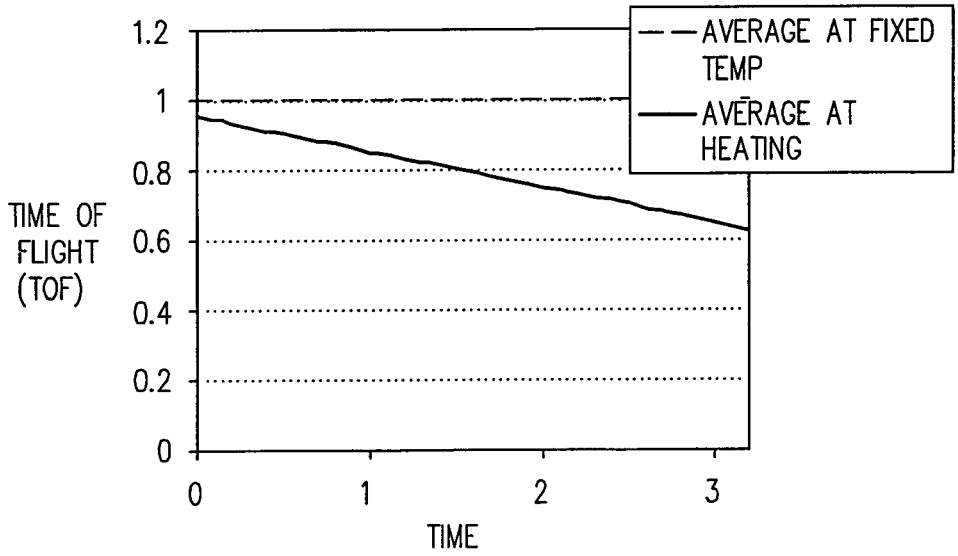
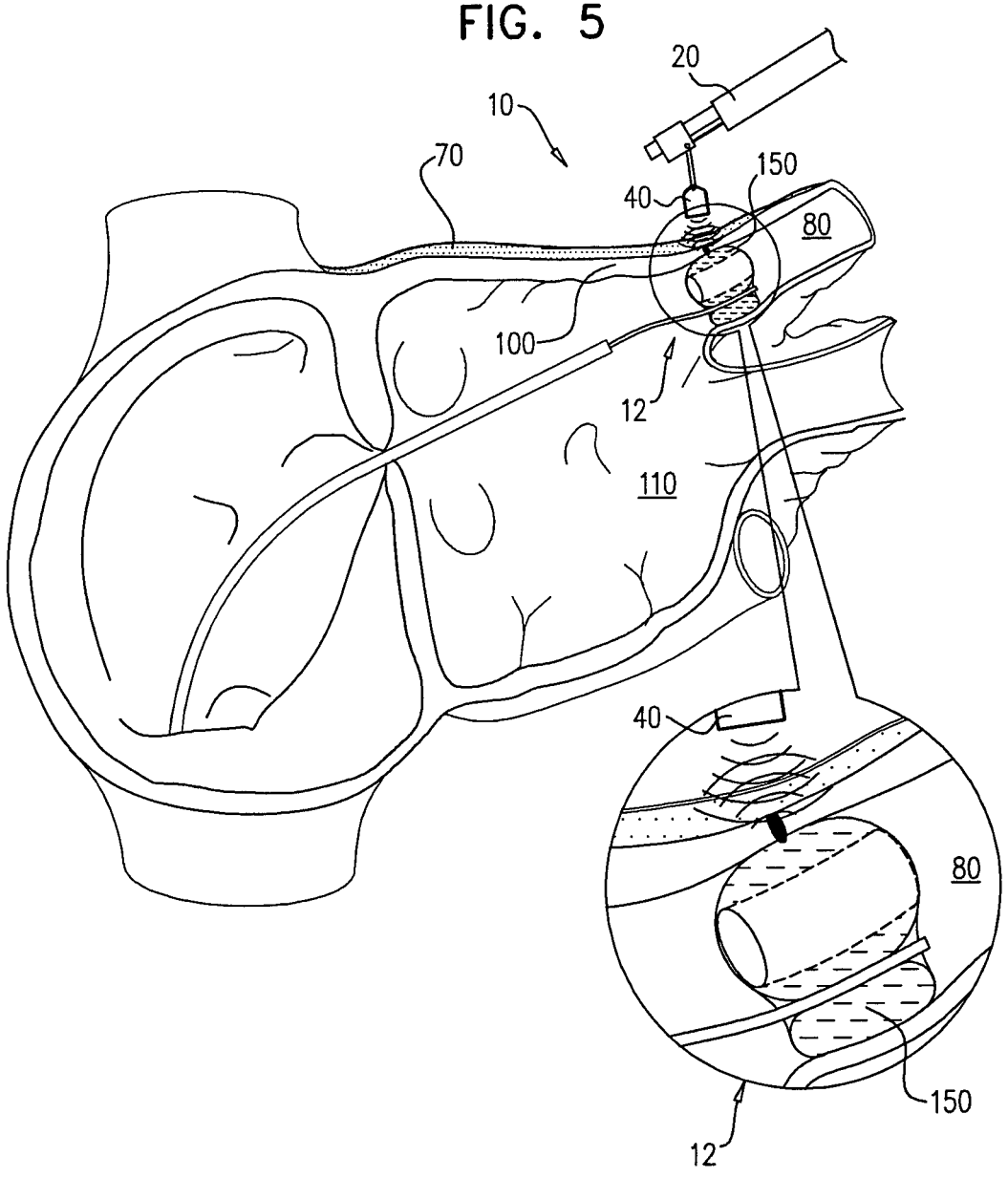

AVERAGE AT FIXED TEMP
AVERAGE AT HEATING
TIME OF FLIGHT (TOF)
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
TIME

FIG. 5



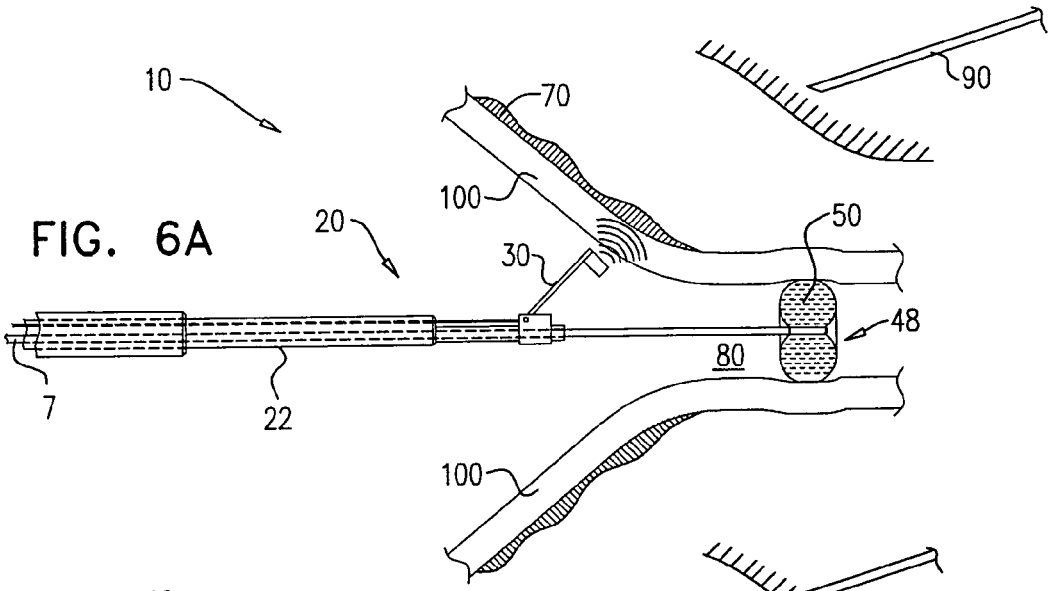


FIG. 6A

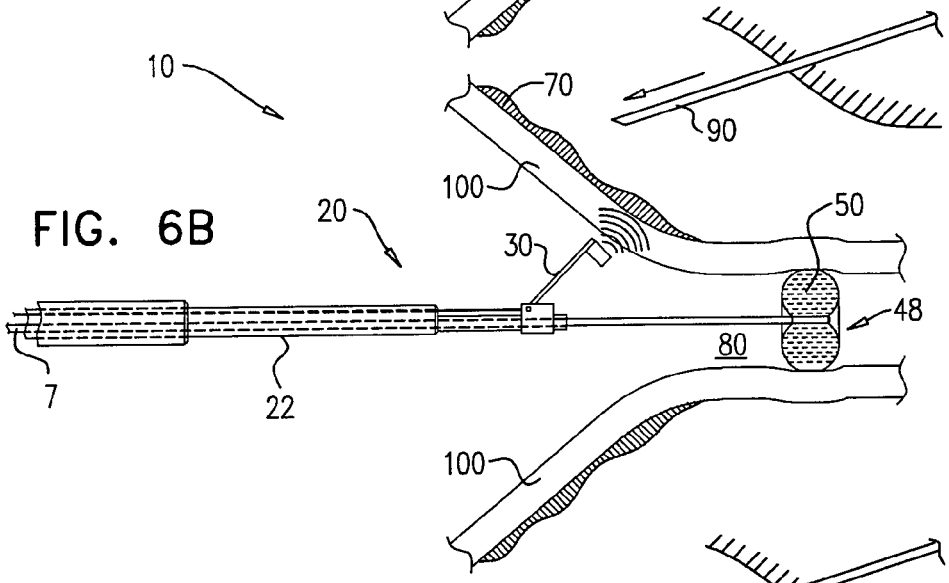


FIG. 6B

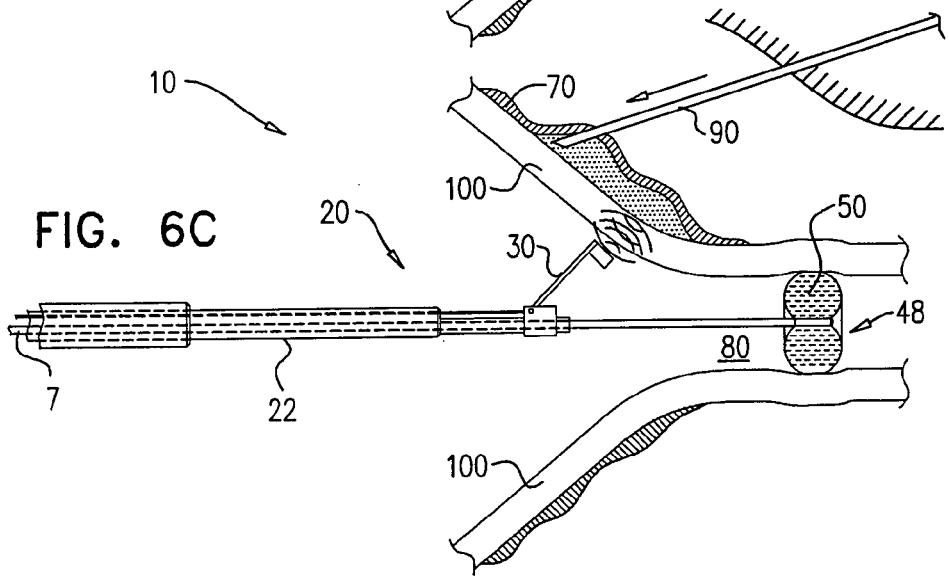


FIG. 6C

FIG. 6D

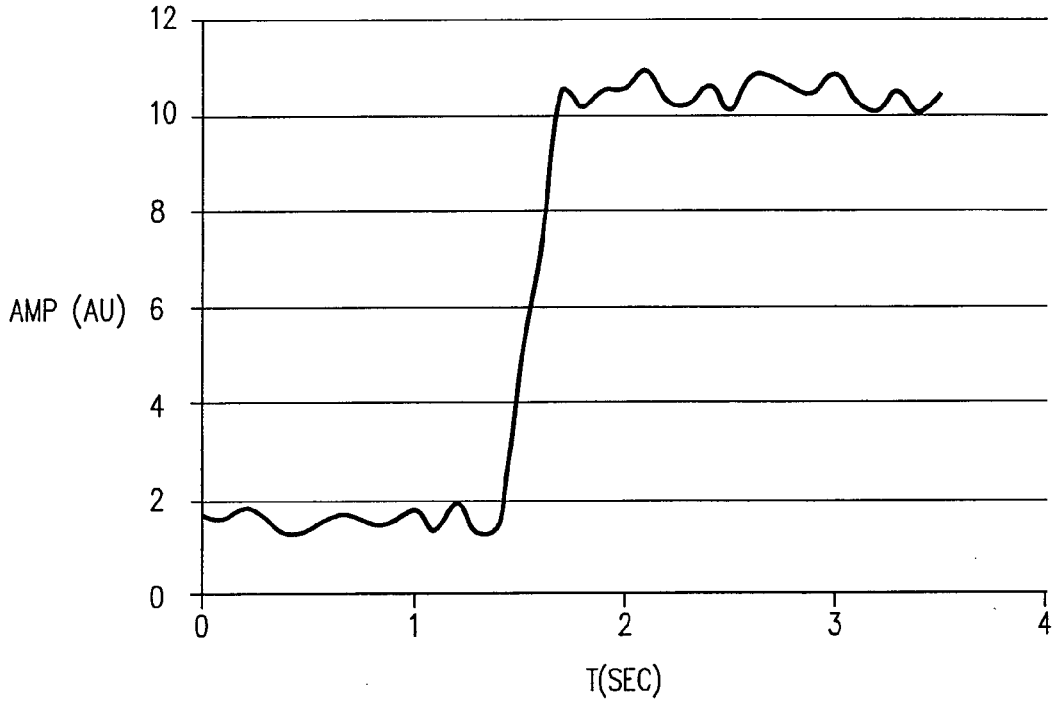


FIG. 7B

US GAS BACKING
AFFIX EFFECT-FULL
THICKNESS NECROSIS
-UP TO 4.5 MM DEEP

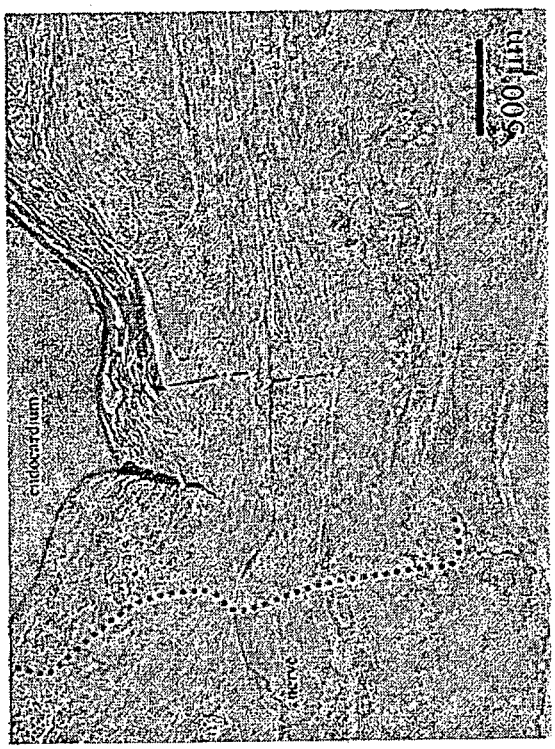
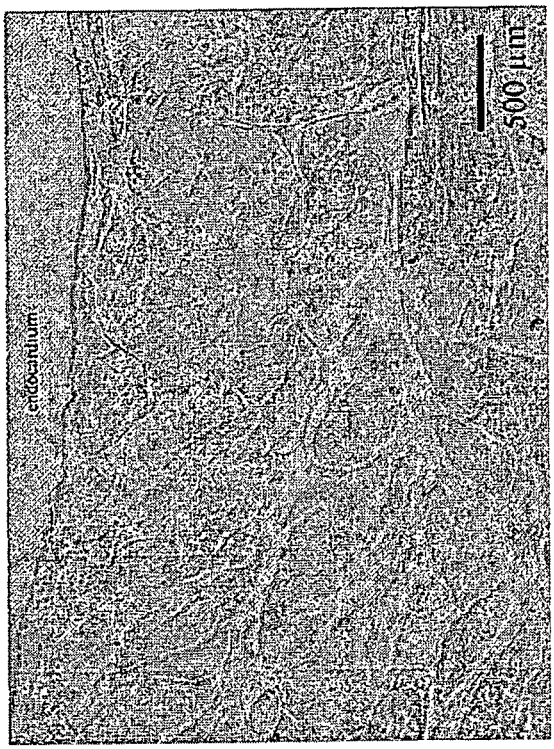


FIG. 7A

US LIQUID BACKING
PATCHY FOCI OF COAGULATION
THICKNESS NECROSIS
-UP TO 0.45 MM DEEP



REFLECTANCE-FACILITATED ULTRASOUND TREATMENT AND MONITORING

CROSS-REFERENCES TO RELATED APPLICATIONS

The present application is the U.S. national phase of PCT Application no. PCT/IL2011/000382 to Tsoref et al., filed May 12, 2011, which claims the priority of and is a continuation-in-part of:

U.S. Ser. No. 12/780,240 to Tsoref et al., entitled "Reflectance-facilitated ultrasound treatment," filed on May 14, 2010, published as US2011-0282249, and issued as U.S. Pat. No. 8,617,150 to Tsoref et al., which is incorporated herein by reference; and

U.S. Ser. No. 13/015,951 to Tsoref et al., entitled "Reflectance-facilitated ultrasound treatment and monitoring" filed on Jan. 28, 2011, published as US 2011-0282203, and issued as U.S. Pat. No. 8,956,346 to Tsoref et al., which is incorporated herein by reference.

FIELD OF THE APPLICATION

Embodiments of the present invention relate generally to treatment of tissue by application of energy thereto, and particularly to ablation of cardiac or other tissue by application of ultrasound energy.

BACKGROUND OF THE APPLICATION

Atrial fibrillation is a common cardiac arrhythmia involving the atria of the heart. During atrial fibrillation, the atria beat irregularly and out of coordination with the ventricles of the heart. Atrial fibrillation disrupts efficient beating of the heart and may result in blood clotting in the atrium leading to serious medical conditions such as strokes.

Atrial fibrillation is generally caused by abnormal electrical activity in the heart. During atrial fibrillation, electrical discharges may be generated by parts of the atria which do not normally generate electrical discharges, such as pulmonary vein ostia in the atrium. Pulmonary vein isolation is a common medical procedure for treatment of atrial fibrillation.

Ablation technologies currently include unipolar and bipolar techniques. The unipolar techniques employ various energy sources, including radiofrequency (RF), microwave, high intensity focused ultrasound (HIFU), laser, and cryogenic energy sources. The bipolar techniques employ RF energy.

SUMMARY OF APPLICATIONS

In some embodiments of the present invention, methods and apparatus are provided for application of ultrasound energy to tissue within a body of a subject. For some applications, the ultrasound energy is applied to treat cardiac arrhythmias, such as atrial fibrillation, ventricular fibrillation, and/or ventricular tachycardia. During a minimally invasive procedure, an ultrasound tool is advanced into an organ of the body, such as a heart chamber. The ultrasound tool comprises at least one ultrasound transducer that is configured to transmit treatment energy, e.g., high intensity focused ultrasound (HIFU), towards myocardial tissue, and in particular towards sites within myocardial tissue which are involved in triggering, maintaining, or propagating cardiac arrhythmias, e.g., in the case of atrial fibrillation, pulmonary vein ostia. The treatment energy applied to the myocardial tissue causes ablation of the tissue. As a result of the ablation, scars typically form in the ablated areas. The scars generally block abnormal electrical pulses generated in the pulmonary vein ostia from propagating into the heart chambers, thereby electrically isolating the pulmonary veins from the atrium and preventing cardiac arrhythmias.

For some applications, prior to application of the treatment energy, a reflection-facilitation element is placed at an extramyocardial site, in a vicinity of the myocardial tissue designated for treatment. The reflection-facilitation element provides a reflective region in the extramyocardial site. Typically, the extramyocardial site is within a "pericardial region," which, as used in the present application, including the claims, consists of one or more regions selected from the group consisting of a region between the pericardium and the myocardium, a region between the visceral pericardium (also known as the epicardium) and the parietal pericardium, and a region outside the pericardium and in contact therewith.

The treatment energy applied by the ultrasound transducer to the sites in the myocardial tissue is reflected from the extramyocardial reflective region back through the myocardial tissue. The treatment energy is thus directed at the myocardial site from two opposing directions, nearly doubling the applied energy, thereby resulting in enhanced ablation of the myocardial tissue. This technique enables the rapid formation of an effective transmural lesion having an increased depth within the myocardium (as viewed from within the heart) and/or increased homogeneity along the depth, compared to that which would be achieved in the absence of the reflection of the ultrasound energy.

For some applications, the reflection-facilitation element comprises a gas-delivery element, which provides the reflective region by delivering a gas to the extramyocardial site. The gas-delivery element, e.g., a needle, is typically inserted through the pericardium and is configured to deliver gas to create a gas-filled pocket within the pericardial region, as defined hereinabove. The gas has a lower density than that of the surrounding tissue within the body, thereby creating a change in acoustic impedance. Due to the change in acoustic impedance, ultrasound waves which reach the gas are reflected. Thus, the gas in the gas-inflated extramyocardial site serves as a reflector for the ultrasound energy. Typically, following inflation of the pericardium with gas, ultrasound energy is applied by the ultrasound transducer in the heart to the designated treatment site in the myocardial tissue that is adjacent to the gas-filled pericardium. The emitted energy reaches the designated treatment site and is reflected by the gas, such that the reflected ultrasound energy passes again through the treatment site.

There is therefore provided in accordance with some applications of the present invention, apparatus including an ultrasound ablation system, which includes:

- a reflection-facilitation element, configured to be placed at a far side of a tissue of a subject, and to provide a reflective region; and
- an ultrasound tool, which includes at least one ultrasound transducer configured to be positioned at a near side of the tissue of the subject, and to ablate the tissue by applying ultrasound energy to the near side of the tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the tissue.

For some applications, the tissue includes myocardial tissue and the far side of the tissue includes an extramyocardial site, and:

- the reflection-facilitation element is configured to be placed at the extramyocardial site of a subject, and to provide an extramyocardial reflective region; and

the at least one ultrasound transducer is configured to be positioned within a heart chamber of the subject, and to ablate the myocardial tissue by applying ultrasound energy to the myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue.

For some applications, the chamber is a left atrium, and the ultrasound transducer is configured to be positioned within the left atrium.

For some applications, the chamber is a chamber selected from the group consisting of the: right atrium, right ventricle, and left ventricle, and the ultrasound transducer is configured to be positioned within the chamber selected from the group.

For some applications, the tissue includes tissue of a subject selected from the group consisting of: nervous tissue, uterine tissue, prostate tissue, lung tissue, and tissue of the gastrointestinal tract and the ultrasound transducer is configured to ablate tissue selected from the group.

For some applications, the ultrasound transducer is configured to apply the ultrasound energy as high intensity focused ultrasound (HIFU) energy.

For some applications, the ultrasound tool further includes an anchoring element, which is configured to temporarily stabilize the tool in the chamber.

For some applications, the anchoring element includes at least one inflatable element, configured to be inflated such that the inflatable element temporarily stabilizes the tool by contacting an inner wall of a blood vessel.

For some applications, the reflection-facilitation element includes a gas-delivery element, configured to provide the reflective region by delivering a gas to the extramyocardial site.

For some applications, the extramyocardial site of the subject is within a pericardial region of the subject that consists of one or more regions selected from the group consisting of: a region between the pericardium and the myocardium, a region between the visceral pericardium and the parietal pericardium, and a region outside the pericardium and in contact therewith, and the reflection-facilitation element is configured to provide the reflective region within the pericardial region.

For some applications, the reflection-facilitation element includes an inflatable element.

For some applications, the reflection-facilitation element includes an acoustic reflector, configured to be delivered to the extramyocardial site of the subject.

For some applications, the reflection-facilitation element is configured to be transthoracically delivered to the extramyocardial site of the subject.

For some applications, the ultrasound tool further includes an arm having a distal end, and the at least one ultrasound transducer is coupled to the distal end of the arm.

For some applications, the ultrasound transducer includes an anticoagulation coating.

For some applications, the reflection-facilitation element includes a mechanical surgical retractor.

For some applications, the ultrasound transducer includes an array of ultrasonic elements.

For some applications, the system further includes a control unit, which is configured to monitor an ultrasonic parameter of the tissue.

For some applications, the control unit is configured to perform an analysis of the parameter, and, responsively to the analysis, to drive the ultrasound transducer to cease ablating the tissue.

For some applications, the ultrasonic parameter is a time of flight of the ultrasound energy applied by the ultrasound transducer and reflected by the reflective region.

For some applications, the control unit is configured to ascertain a temperature of the tissue responsively to the time of flight.

For some applications, the control unit is configured to use signal processing to eliminate sinusoidal behavior exhibited by the time of flight due to atrial contractions.

For some applications, the control unit is configured to use an average moving window to eliminate the sinusoidal behavior.

For some applications, the ultrasonic parameter is selected from the group consisting of: an amplitude of the ultrasound energy applied by the ultrasound transducer and reflected by the reflective region, a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy.

For some applications, an additional tool is configured to ablate the tissue subsequently to the ultrasound transducer applying ultrasound energy to the tissue.

For some applications, the additional tool includes a tool selected from the group consisting of: a radiofrequency (RF) tool, an ultrasound tool, and a cryoablation tool.

There is further provided in accordance with some applications of the present invention, apparatus including an ultrasound ablation system, which includes:

a reflection-facilitation element, configured to be placed within a heart chamber of a subject, and to provide an intracardiac reflective region; and

an ultrasound tool, which includes at least one ultrasound transducer configured to be positioned at an extramyocardial site of the subject, and to ablate myocardial tissue by applying ultrasound energy to the myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue.

For some applications, the chamber is a left atrium, and the reflection-facilitation element is configured to be placed within the left atrium, and to provide the intracardiac reflective region within the left atrium.

For some applications, the chamber is a chamber selected from the group consisting of the: right atrium, right ventricle, and left ventricle and the reflection-facilitation element is configured to be positioned within the chamber selected from the group.

For some applications, the ultrasound transducer is configured to apply the ultrasound energy as high intensity focused ultrasound (HIFU) energy.

For some applications, the extramyocardial site of the subject is within a pericardial region of the subject that consists of one or more regions selected from the group consisting of: a region between the pericardium and the myocardium, a region between the visceral pericardium and the parietal pericardium, and a region outside the pericardium and in contact therewith, and the ultrasound transducer is configured to be positioned within the pericardial region.

There is yet further provided in accordance with some applications of the present invention, a method including:

advancing, into a heart chamber of a subject, an ultrasound tool that includes at least one ultrasound transducer;

providing a reflective region at an extramyocardial site of the subject; and

activating the ultrasound transducer to ablate myocardial tissue by applying ultrasound energy to the myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue of the subject.

For some applications, providing the reflective region includes using a reflective-facilitation element to provide the reflective region.

For some applications, the chamber is a left atrium, and advancing includes advancing the ultrasound tool into the left atrium.

For some applications, activating includes activating the ultrasound transducer to apply the ultrasound energy as high intensity focused ultrasound (HIFU) energy.

For some applications, the method includes applying radiofrequency (RF) energy to the myocardial tissue following activating the ultrasound transducer to ablate myocardial tissue.

For some applications, advancing the ultrasound tool includes temporarily stabilizing the ultrasound tool in the chamber using an anchoring element.

For some applications, providing the reflective region includes delivering a gas to the extramyocardial site.

For some applications, the extramyocardial site is within a pericardial region of the subject that consists of one or more regions selected from the group consisting of: a region between the pericardium and the myocardium, a region between the visceral pericardium and the parietal pericardium, and a region outside the pericardium and in contact therewith, and providing the reflective region includes providing the reflective region within the pericardial region.

For some applications, providing the reflective region includes inflating an inflatable element at the extramyocardial site with a fluid selected from the group consisting of: a gas, and a mixture of a liquid and a gas.

For some applications, providing the reflective region includes delivering an acoustic reflector to the extramyocardial site.

For some applications, providing the reflective region includes inserting a mechanical surgical retractor into the extramyocardial site.

For some applications, the ultrasound transducer includes an array of ultrasonic elements, and activating the ultrasound transducer includes activating the array of ultrasonic elements.

For some applications, activating further includes monitoring an ultrasonic parameter of the myocardial tissue.

For some applications, activating further includes performing an analysis of the parameter, and, responsively to the analysis, ceasing ablating the myocardial tissue.

For some applications, the parameter is a time of flight of the ultrasound energy applied by the ultrasound transducer and reflected by the reflective region.

For some applications, monitoring includes ascertaining a temperature of the tissue responsively to the time of flight.

For some applications, monitoring includes using signal processing to eliminate sinusoidal behavior exhibited by the time of flight due to atrial contractions.

For some applications, using the signal processing includes using an average moving window to eliminate the sinusoidal behavior.

For some applications, the ultrasonic parameter is selected from the group consisting of an amplitude of the ultrasound energy applied by the ultrasound transducer and reflected by the reflective region, a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy.

There is still further provided in accordance with some applications of the present invention, a method including:

providing a reflective region within a heart chamber of a subject;

positioning at least one ultrasound transducer at an extramyocardial site of the subject; and

activating the ultrasound transducer to ablate myocardial tissue by applying ultrasound energy to the myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue of the subject.

For some applications, providing the reflective region includes using a reflective-facilitation element to provide the reflective region.

For some applications, providing the reflective region includes inserting an inflatable element into the chamber, and inflating the inflatable element with a fluid selected from the group consisting of a gas, and a mixture of a liquid and a gas.

For some applications, the chamber is a left atrium, and providing includes providing the reflective region within the left atrium.

For some applications, activating includes activating the ultrasound transducer to apply the ultrasound energy as high intensity focused ultrasound (HIFU) energy.

For some applications, the extramyocardial site of the subject is within a pericardial region of the subject that consists of one or more regions selected from the group consisting of: a region between the pericardium and the myocardium, a region between the visceral pericardium and the parietal pericardium, and a region outside the pericardium and in contact therewith, and positioning includes positioning the at least one ultrasound transducer within the pericardial region.

There is additionally provided in accordance with some applications of the present invention, a method including:

providing a reflective region at a far side of tissue of a subject; and

ablating the tissue by applying ultrasound energy to a near side of the tissue such that at least a portion of the applied energy is reflected onto the tissue by the reflective region.

For some applications, the tissue includes myocardial tissue and the far side of the tissue includes an extramyocardial site, and:

providing the reflective region at the far side of the tissue includes providing the reflective region at the extramyocardial site; and

ablating the tissue includes ablating the myocardial tissue.

For some applications, the tissue includes tissue of a subject selected from the group consisting of: nervous tissue, uterine tissue, prostate tissue, lung tissue, and tissue of the gastrointestinal tract, and ablating the tissue includes ablating the selected tissue.

For some applications, providing the reflective region includes placing a reflective-facilitation element at the far side of the tissue, and using the reflective-facilitation element to provide the reflective region.

For some applications, providing the reflective region includes providing a gas at the far side.

There is still additionally provided in accordance with some applications of the present invention, a method including:

providing a reflective region at a far side of tissue of a subject;

assessing whether the reflective region is in a desired location, by means of acoustic sensing; and

in response to assessing that the reflective region is in the desired location, activating an ultrasound transducer to ablate the tissue by applying ultrasound energy to a near side of the tissue, such that at least a portion of the transmitted energy is reflected by the reflective region onto the tissue of the subject.

For some applications, assessing includes:

applying non-ablating ultrasound energy to the near side of the tissue, such that at least a portion of the applied energy is reflected onto the tissue by the reflective region; and

monitoring an ultrasound parameter of the reflected energy.

For some applications, monitoring the ultrasound parameter includes monitoring an amplitude of the ultrasound energy reflected by the reflective region.

For some applications, the ultrasound parameter is selected from the group consisting of: a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy, and monitoring the ultrasound parameter includes monitoring the selected ultrasound parameter.

For some applications, assessing includes receiving sound generated by the providing of the reflective region.

For some applications, assessing includes determining whether the reflective region is within a pericardium of the subject.

For some applications, providing the reflective region includes transthoracically advancing a reflection-facilitation element toward the desired location.

For some applications, providing the reflective region includes transvenously advancing a reflection-facilitation element toward the desired location.

For some applications, the desired location is within a pericardial region of the subject that consists of one or more regions selected from the group consisting of: a region between the pericardium and the myocardium, a region between a visceral pericardium and a parietal pericardium, and a region outside the pericardium and in contact therewith, and providing the reflective region includes providing the reflective region within the pericardial region.

There is yet additionally provided in accordance with some applications of the present invention, a method including:

advancing into a heart chamber of a subject, an ultrasound tool that includes at least one ultrasound transducer;

advancing a reflection-facilitation element towards an extramyocardial site of a subject;

operating the reflection-facilitation element to release a reflection-facilitation agent to provide a reflective region at the extramyocardial site of the subject;

activating the ultrasound transducer to apply ultrasound energy to myocardial tissue of the subject such that at least a portion of the transmitted energy is reflected by the reflective region onto the ultrasound transducer; and

monitoring an ultrasound parameter of the reflected energy.

There is further additionally provided in accordance with some applications of the present invention, a method for monitoring ablation of a tissue site, the method including:

during a first time period, activating an ultrasound transducer to apply high intensity ultrasound energy to the tissue site, capable of ablating the tissue;

during a second time period, subsequent to the first time period, activating the ultrasound transducer to apply low intensity ultrasound energy to the tissue site such that at least a portion of the transmitted energy is reflected by the tissue onto the ultrasound transducer; and

monitoring an ultrasound parameter of the reflected energy.

For some applications, the method includes the step of performing an analysis of the ultrasound parameter, and, responsively to the analysis, determining a level of ablation of the tissue site.

For some applications, the method includes the step of performing an analysis of the ultrasound parameter, and, responsively to the analysis, determining a continuity of an ablation lesion throughout the tissue site.

For some applications, monitoring the ultrasound parameter includes monitoring an amplitude of the ultrasound energy reflected by the reflective region.

For some applications, the ultrasound parameter is selected from the group consisting of: a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy, and monitoring the ultrasound parameter includes monitoring the selected ultrasound parameter.

There is still additionally provided in accordance with some applications of the present invention, apparatus including an ultrasound monitoring system, which includes:

a reflection-facilitation element, configured to be advanced towards an extramyocardial site of a subject, and to release a reflection facilitation agent to provide an extramyocardial reflective region; and

an ultrasound tool, which includes at least one ultrasound transducer configured to be positioned within a heart chamber of the subject, and to apply ultrasound energy to myocardial tissue such that at least a portion of the transmitted energy is reflected by the reflective region onto the myocardial tissue.

There is yet additionally provided in accordance with some applications of the present invention, apparatus for monitoring ablation of a tissue site, the apparatus including:

an ultrasound tool, which includes at least one ultrasound transducer configured to be positioned at a tissue site of a subject and configured to apply ablating ultrasound energy to the tissue site during a first time period, and to apply non-ablating ultrasound energy to the tissue site, such that at least a portion of the transmitted energy is reflected by the tissue onto the ultrasound transducer during a second period of time; and

a processor configured to monitor an ultrasound parameter of the reflected energy.

For some applications, the tissue site includes a heart chamber of the subject, and the ultrasound transducer is configured to be positioned within the heart chamber.

For some applications, the chamber is a left atrium, and the ultrasound transducer is configured to be positioned within the left atrium.

For some applications, the chamber is a chamber selected from the group consisting of the: right atrium, right ventricle, and left ventricle, and the ultrasound transducer is configured to be positioned within the chamber selected from the group.

For some applications, the tissue site includes tissue of a subject selected from the group consisting of: nervous tissue, uterine tissue, prostate tissue, lung tissue, and tissue of the gastrointestinal tract and the ultrasound transducer is configured to be positioned at a tissue site selected from the group.

For some applications, the processor is further configured to perform an analysis of the ultrasound parameter, and, responsively to the analysis, to determine a level of ablation of the tissue site.

For some applications, the processor is further configured to perform an analysis of the ultrasound parameter, and, responsively to the analysis, to determine a continuity of an ablation lesion throughout the tissue site.

For some applications, the processor is further configured to perform an analysis of a plurality of ultrasound parameters, and, responsively to the analysis, to determine a continuity of an ablation lesion throughout the tissue site.

For some applications, the ultrasound parameter includes an amplitude of the ultrasound energy reflected by the reflective region, and the processor is configured to monitor the amplitude of the ultrasound energy reflected by the reflective region.

For some applications, the ultrasound parameter is selected from the group consisting of: a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy, and the processor is configured to monitor the selected ultrasound parameter.

There is still further provided in accordance with some applications of the present invention, apparatus including an ablation system, which includes:

an ablation tool configured to be positioned at a near side of the tissue of the subject, and to ablate the tissue; and

a gas-delivery element, configured to be placed at a far side of a tissue of a subject, and to provide a gas-filled region configured to increase efficacy of tissue ablation.

For some applications, the ablation tool includes a radiofrequency (RF) ablation tool configured to ablate the tissue by applying RF energy to the near side of the tissue.

For some applications, the ablation tool includes a cryoablation tool.

There is additionally further provided accordance with some applications of the present invention, a method including:

providing a gas-filled region at a far side of tissue of a subject; and

activating an ablation tool at a near side of the tissue to cause ablation of the tissue.

For some applications, the ablation tool includes a radiofrequency (RF) ablation tool and activating the ablation tool includes activating the radiofrequency (RF) ablation tool to apply energy to the near side of the tissue.

For some applications, the ablation tool includes a cryoablation tool and activating the ablation tool includes activating the cryoablation tool.

The present invention will be more fully understood from the following detailed description of embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-B are schematic illustrations of an ultrasound ablation system, in accordance with some applications of the present invention;

FIGS. **2**A-F are schematic illustrations of the use of the ultrasound system of FIGS. **1**A-B for application of ultrasound energy to tissue, in accordance with some applications of the present invention;

FIGS. **2**G-J are schematic illustrations of alternative configurations of the system of FIGS. **1**A-B, in accordance with respective applications of the present invention;

FIGS. **3**A-C are schematic cross-sectional views of the atria showing operation of the system for application of ultrasound energy to tissue of the left atrium, in accordance with some applications of the present invention;

FIGS. **4**A-B are graphs showing changing parameters in cardiac tissue resulting from heating of the tissue, as determined by simulated ultrasound monitoring, in accordance with some applications of the present invention;

FIG. **5** is a schematic illustration of an alternative configuration of the system of FIGS. **1**A-B, in accordance with an application of the present invention;

FIGS. **6**A-D are schematic illustrations of the use of the ultrasound system of FIGS. **1-3** for monitoring application of ultrasound energy to tissue, in accordance with some applications of the present invention; and

FIGS. **7**A-B are experimental results showing histological images of cardiac tissue following application of ultrasound energy thereto, in accordance with some applications of the present invention.

DETAILED DESCRIPTION OF APPLICATIONS

Reference is made to FIGS. **1**A-B, which are schematic illustrations of an ultrasound ablation system **10**, in accordance with some applications of the present invention. Ablation system **10** comprises an ultrasound tool **20** and a reflection-facilitation element **12**, which, as described hereinbelow, provides a reflective region. Ultrasound tool **20** comprises at least one ultrasound transducer **40**. Tool **20** typically further comprises a catheter **22**, for facilitating advancement of the tool into a chamber of a heart of a subject. Tool **20** also may comprise a proximal shaft **24**, which may house a distal shaft **23**, which comprises a proximal portion **31**, a distal portion **32**, and a hinge **44**. The hinge connects the proximal and distal portions, and facilitates rotation of different elements of tool **20**. (In this context, in the specification and in the claims, "proximal" means closer to the orifice through which the tool is originally placed into the body, and "distal" means further from this orifice.) It is to be noted that hinge **44** is provided by way of illustration and not limitation. Any suitable element that may facilitate rotation and/or a configurational change of tool **20** may be used, e.g., a spring or a bendable portion of tool **20**.

For some applications, distal portion **32** comprises an arm **30** that is coupled to hinge **44**. Arm **30** typically comprises, at a distal end thereof, the at least one ultrasound transducer **40**. Tool **20** may comprise a plurality of arms **30** and any number of ultrasound transducers **40**. For some applications, ultrasound transducer **40** is coupled to an element of tool **20** other than the arm.

For some applications, ultrasound tool **20** further comprises an anchoring element **48**, which is configured to temporarily stabilize the tool during application of the treatment energy. For example, the anchoring element may temporarily anchor the distal end of tool **20** in a pulmonary vein. For some applications, as shown in the figures, anchoring element **48** comprises an inflatable element **50**, e.g., comprising a balloon, which may be coupled to the distal end of distal portion **32** of shaft **23**. Optionally the inflatable element is shaped so as to provide a passage therethrough for blood flow, such as described hereinbelow with reference to FIG. **5**. Alternatively or additionally, for some applications, anchoring element **48** comprises a mechanical anchoring element. For example, the mechanical anchoring element may comprise a flexible metal

element (e.g., comprising Nitinol) configured to engage the walls of the pulmonary vein, without blocking blood flow. For example, the metal element may have a U-shape or J-shape, such as provided on the Pulmonary Vein Ablation Catheter® (PVAC®) (Medtronic Ablation Frontiers LLC, Carlsbad, Calif.), or a flower-shaped element, such as provide by the Multi-Array Septal Catheter® (MASC®) (Medtronic Ablation Frontiers LLC, Carlsbad, Calif.).

Tool **20** is shown in FIG. **1**A in a collapsed state thereof. In its collapsed state, tool **20** assumes a smaller dimension than in its expanded, operative state. Thus, in its collapsed state, the tool is configured for insertion into a blood vessel in a location remote from the heart and for advancement within a chamber of the heart. Accordingly, inflatable element **50** is shown in FIG. **1**A in a deflated state.

Reference is now made to FIG. **1**B, which shows tool **20** in the expanded, operative state thereof. Tool **20** is typically configured to be delivered to a location designated for treatment within a body of a subject, e.g., a chamber of the subject's heart. Once delivered to the location, tool **20** is transformed into the operative state as shown in FIG. **1**B. In the operative state, hinge **44** typically facilitates deflection of arm **30**, such that arm **30** is deflected laterally as indicated by arrow **12**A (e.g., by 90 degrees, as shown) from a position that is aligned with a longitudinal axis of tool **20**. Arm **30** may be deflected at any angle up to 180 degrees, such that ultrasound transducer **40** is aimed at any desired treatment site. Optionally, a control wire **15** is controllable by a physician in order to adjust the angle of arm **30**.

Typically, ultrasound transducer **40** is configured to emit high intensity focused ultrasound (HIFU) waves towards a target tissue. For some applications, a surface of transducer **40** is coated with an anticoagulation coating, in order to reduce coagulation of blood on the transducer as a result of heating of the transducer. For example, the anticoagulation coating may comprise a heparin anticoagulant coating such as Carmeda BioActive Surface (CBAS®) as provided by Carmeda AB, a W.L. Gore company. Additionally or alternatively, the transducer is actively cooled (e.g., using a cooled liquid or a thermoelectric element). For some applications, the transducer is passively cooled by being shaped and oriented in a way that facilitates the flow of blood over the transducer. For example, the transducer may be convex or concave, and may face oncoming flow exiting blood vessel **80**, such that the flow convectively drives away heat accumulating at the surface of the transducer. Alternatively, if the transducer is flat, then to achieve passive cooling, the transducer is typically positioned near to the orifice of blood vessel **80** at at least 10 degrees, e.g., at least 90 degrees, but such that it does not directly face the oncoming flow.

For some applications, distal portion **32** comprises a telescopically collapsible and extendable element **34**, which facilitates the telescopic extension and collapse of distal portion **32**.

Inflatable element **50** is shown in FIG. **1**B in its inflated state.

Reference is made to FIGS. **2**A-G, which are schematic illustrations of a system **10** for application of ultrasound energy to tissue within a body of a subject, in accordance with some applications of the present invention. Tool **20** is configured for treatment by ultrasound energy of a region within a body of a subject. Typically, tool **20** is configured for ablating tissue, e.g., cardiac tissue. For some applications, tool **20** is inserted into a chamber of the heart and disposed in an area that is adjacent to an orifice of a blood vessel **80**, e.g., adjacent to a pulmonary vein ostium in the left atrium of the heart. Tool **20** is configured to ablate tissue in a vicinity of the orifice of the blood vessel in order to electrically isolate the blood vessel.

FIG. **2**A shows tool **20** being advanced to a location within the heart that is adjacent to an orifice of a blood vessel. The tool is advanced in a collapsed state thereof, as described hereinabove with reference to FIG. **1**A.

FIGS. **2**B-C show the opening of tool **20** to an operative state. Tool **20** is shown disposed within a chamber of the heart, e.g., the left atrium. It is to be understood that the scope of the present invention includes disposing tool **20** in any other chamber of the heart for treatment of tissue thereof, including the left or right ventricle for treatment of tissue of the ventricle.

Tool **20** is located adjacent to an orifice of a blood vessel **80**, e.g., a pulmonary vein ostium, and to cardiac tissue, e.g., an atrial wall **100**. Hinge **44** typically facilitates deflection of arm **30** such that arm **30** is deflected laterally, as indicated by arrow **12**A (e.g., by between 30 and 90 degrees, such as by 45 degrees, as shown) from a position that is aligned with a longitudinal axis of tool **20**. The angle of deflection of arm **30** is typically controllable by the physician during a procedure. Deflection of arm **30** brings ultrasound transducer **40** into proximity of (e.g., in contact with or within a few millimeters of) the endocardium of cardiac tissue designated for ablation treatment, such that ultrasound transducer **40** is aimed at the designated site. There is generally no need for firm contact between ultrasound transducer **40** and the endocardium. In some applications, the site designated for treatment is cardiac tissue in the atrial wall surrounding an orifice of a blood vessel, e.g., a pulmonary vein ostium.

For some applications, distal portion **32** of tool **20** is telescopically extended into blood vessel **80** in the direction indicated by an arrow **13**A. For some applications, tool **20** comprises inflatable element **50**, e.g., a balloon, coupled to the distal end of distal portion **32**. For applications in which tool **20** comprises anchoring element **48**, during opening of tool **20** into an operative state, and subsequent application of treatment energy, the anchoring element stabilizes the tool against the wall of blood vessel **80** during application of treatment energy and rotation of arm **30** or another element of tool **20** (described hereinbelow). For example, for applications in which anchoring element **48** comprises inflatable element **50**, inflatable element **50** is inflated (by filling the inflatable element with fluid, i.e., a gas or a liquid) to apply pressure to a wall of blood vessel **80**, in order to stabilize and maintain tool **20** in place. Inflatable element **50** may be inflated prior to deflection of arm **30**, so as to stabilize and maintain tool **20** in place during the deflection of arm **30** and subsequent application of treatment energy. For some applications, inflatable element **50** comprises an annular inflatable element that surrounds a distal portion of tool **20**.

It is to be noted that an inflation conduit **7** is coupled at a distal end thereof to inflatable element **50**, and extends through a lumen of shaft **23** and toward distal portion **32** of tool **20**. When the operating physician desires to inflate element **50**, fluid (i.e., a gas or liquid) is delivered via the conduit toward inflatable element **50** from a fluid source that is disposed outside the body of the subject. The fluid may be pressurized.

Reference is still made to FIG. **2**C. For some applications, prior to application of energy, reflection-facilitation element **12** is placed at an extramyocardial site, in a vicinity of the myocardial tissue designated for treatment. The reflection-facilitation element provides a reflective region in the extramyocardial site. For some applications, the reflection-facilitation element comprises a gas-delivery element **90**

which delivers a gas to the extramyocardial site, e.g., within the pericardial region, as defined hereinabove. Gas-delivery element **90**, which may, for example, comprise a needle, is typically inserted into or through the pericardium, and is configured to deliver gas to create a gas-filled pocket within the pericardial region, as defined hereinabove. For some applications, needle **90** is inserted through the central port, under the collarbone. Optionally, a small camera is inserted with the needle to provide image guidance during the insertion procedure.

Reference is made to FIG. **2**D, which shows system **10** positioned for applying ablating treatment to a target site in atrial wall **100**. The pericardial region is shown in an inflated state, with gas having been delivered to the region between pericardium **70** and the myocardium. Alternatively, the pericardial region may be inflated by delivering the gas to the region between the visceral and parietal pericardial layers (configuration not shown). Arm **30** of tool **20** is deflected such that transducer **40** is aimed at a target site in atrial wall **100** designated for treatment. Additionally, for some applications, anchoring element **48** is deployed to stabilize and maintain tool **20** in place during subsequent application of treatment.

FIG. **2**E is a schematic illustration of system **10** being operated to treat the subject. Ultrasound transducer **40** typically transmits high intensity focused ultrasound waves, directly heating the tissue in the acoustic focal volume (which may be cigar-shaped). For some applications, ultrasound energy emitted by transducer **40** is focused by using a curved piezoelectric element and/or by using a lens and/or by using a plurality of ultrasound transducers **40**. A focal point of transducer **40** is typically located in atrial wall **100**, and the treatment energy transmitted by transducer **40** is generally capable of ablating myocardial tissue in atrial wall **100**. For other applications, ultrasound transducer **40** transmits non-focused ultrasound waves. Additionally or alternatively, ultrasound transducer **40** transmits low intensity focused or non-focused ultrasound waves. For some applications, ultrasound transducer **40** is configured to transmit power at at least 1 watt, e.g., at least 10 watts, and/or less than 100 watts, e.g., between 10 and 100 watts, e.g., between 15 and 50 watts. For some applications, ultrasound transducer **40** is configured to transmit power that is more than 100 watts. Ablating ultrasound waves are shown passing through the tissue to reach a gas-filled region of pericardium **70**. For some applications, ultrasound transducer **40** is configured to generate ultrasound energy at a frequency having a value that is at least 100 kHz, e.g., at least 1.5 MHz, and/or less than 20 MHz, e.g., less than 10 MHz, e.g., less than 5 MHz. At low frequencies (around 100-500 kHz), tissue destruction is primarily caused by cavitation, while at higher frequencies tissue destruction is primarily caused by a thermal effect. When creating the thermal effect, it is generally desirable to elevate the wall temperature to 60-80 C. For some applications, for creating the thermal effect it is sufficient to elevate wall temperature to a temperature of 50 C for a longer time period.

FIG. **2**F shows ablating treatment energy being applied by ultrasound transducer **40** to a specific target site in atrial wall **100** and reaching a gas-filled region of pericardium **70**. The gas is of lower density than the surrounding tissue in the body, thereby creating a change in acoustic impedance. Due to the change in acoustic impedance, the gas functions as a reflective region, similar to a mirror, along atrial wall **100** and ultrasound waves which reach the gas are reflected. Thus, ultrasound waves are typically reflected from the reflective region, back through myocardial tissue in atrial wall **100**, resulting in temperature elevation and enhanced ablation of the myocardial tissue. Reflection of the ultrasound energy such that it passes through the tissue for a second time achieves what may be considered a bipolar effect, thereby increasing the thermal effect of the ultrasound energy, resulting in the rapid formation of an effective, transmural, long-lasting lesion in the tissue. Typically, the transmural lesion is formed rapidly at each radial site in 0.1-20 seconds, e.g., in about one second.

As shown in FIG. **2**F, reflected return waves pass through the tissue generally simultaneously with the transmitted waves, increasing the amount of energy that passes through the tissue and achieving improved ablation of the tissue. Increased ablation of the tissue near the ostium of blood vessel **80** typically results in improved isolation of the blood vessel **80** and reduced occurrence of cardiac arrhythmia.

As shown in FIG. **2**F, tool **20** (e.g., arm **30**, another element of the tool, or the entire tool) can be rotated in a direction indicated by an arrow **14**A (and/or in the opposite direction), such that ultrasound transducer **40** can be aimed at any desired location around an orifice of blood vessel **80**. Rotation of tool **20** allows circumferential ablation surrounding the orifice of blood vessel **80**, e.g., the pulmonary vein ostium, such that blood vessel **80** is electrically isolated from other areas of the heart, blocking conduction of undesired pulses from blood vessel **80** into the heart. Thus, tool **20** or an element thereof is typically rotated a full 360 degrees. Typically, anchoring element **48** does not rotate as arm **30** is rotated. For example, a hinge may be provided at distal portion **32** or at extendable element **34** that allows the rotation of arm **30** without the rotation of anchoring element **48**.

Typically, following the creation of the first lesion in the ablation site in atrial wall **100**, tool **20** is rotated slightly, e.g., by between 1 and 10 degrees (e.g., between 2.5 and 7.5 degrees), such that ultrasound transducer **40** is now aimed at an adjacent location of atrial wall **100**, for creation of an additional lesion. This procedure is typically repeated until a 360-degree circumferential lesion surrounding the orifice of blood vessel **80** is formed. For some applications, transducer **40** is rotated slowly while continuously transmitting ultrasound energy, thus creating a continuous circular lesion surrounding the orifice of blood vessel **80**. For some applications, the rotation is performed manually by the physician performing the procedure. Alternatively, the rotation is performed by a motor. For some applications, system **10** comprises a control unit that senses when each individual lesion has been formed (e.g., by monitoring temperature, as described hereinbelow with reference to FIGS. **4**A-B, e.g., by sensing that a desired temperature of 60 to 80 degrees has been obtained). Optionally, upon sensing that each lesion has been formed, the control unit drives the motor to rotate the tool or an element thereof, such that transducer **40** applies energy to a subsequent location.

For some applications, transducer **40** is configured to provide the operating physician with information regarding the path of ablation. For such applications, transducer **40** may be configured to indicate a direction that the transducer is facing such that the path of ablation is indicated on a mapping system viewed by the physician.

Reference is made to FIGS. **2**G-J, which are schematic illustrations of alternative configurations of system **10**, in accordance with respective applications of the present invention. For some applications, as shown in FIG. **2**G, reflection-facilitation element **12** comprises a shaped acoustic reflector **120** (e.g., having a spherical, parabolic, or ellipsoidal shape), which may comprise, for example, a metal. Reflector **120** is typically placed at an extramyocardial site, e.g., within the pericardial region, as defined hereinabove, such as outside and typically in contact with the pericardium. The reflector

causes ultrasound waves transmitted from transducer **40** to reflect back through the myocardial tissue, resulting in enhanced ablation of the myocardial tissue. Reflector **120** is placed facing ultrasound transducer **40**, and is moved as the transducer is rotated. Larger reflectors cover larger areas, and thus need be repositioned fewer times than smaller reflectors. For some applications, system **10** verifies proper positioning of reflector **120** by measuring the amplitude of the ultrasound echo received by transducer **40**. The amplitude of the echo is small if the reflector is not properly positioned, and increases sharply when the reflector is properly positioned over the transducer.

Alternatively, reflection-facilitation element **12** comprises another material that has an acoustic impedance different from that of water, typically substantially different. For example, the element may comprise a sponge, an expanded polystyrene foam (e.g., Styrofoam®, Dow Chemical Company), or another material that contains a large amount of air. Ultrasound energy that is transmitted towards tissue of atrial wall **100** is reflected due to the different acoustic impedance, such that the return energy waves pass again through the tissue.

For some applications, reflection-facilitation element **12** comprises a mechanical surgical retractor, which is configured to separate the pericardium from the heart. The space thus created naturally fills with gas, thereby creating the reflective region. Surgical retractors are widely available from numerous manufacturers.

Reference is made to FIG. **2**H. For some applications, reflection-facilitation element **12** comprises an inflatable element **122**, e.g., a balloon. The inflatable element is inserted into the pericardial region, as defined hereinabove, typically between the pericardium **70** and atrial wall **100**, or pressed against the outside of the pericardium. For some applications, in addition to inflatable element **122**, reflection-facilitation element **12** provides a reflective region in the pericardial region by delivering gas to the region that surrounds inflatable element **122**.

The inflatable element is typically inflated with a fluid having a lower density than water, such as a gas (e.g., carbon dioxide) or a mixture of fluid and gas. The low-density fluid functions as the reflective region described hereinabove. Ultrasound energy that is transmitted towards tissue of atrial wall **100** is reflected due to the fluid-filled (e.g., gas-filled) balloon, such that the return energy waves pass again through the tissue. For some applications, inflatable element **122** is coupled to a double-channeled catheter. A first one of the channels is in fluid communication with the interior of the inflatable element, for delivering the fluid (gas or mixture of gas and liquid) to inflate the inflatable element. A second one of the channels is positioned in fluid communication with the pericardial region, typically the region between the pericardium and the myocardium. The second channel is used to deliver a gas to the pericardial region. For some applications, the channels are defined by two tubes, an inner tube positioned within an outer tube. For example, the inner tube may be in fluid communication with the inflatable element, and the outer tube may be in fluid communication with the pericardial region. For example, the outer tube may be shaped so as to define slots therethrough, through which the gas is injected into the pericardial region. For some applications, the inflatable element helps separate the membrane of the myocardium from that of the pericardium, functioning as a retractor.

Reference is made to FIG. **2**I. For some applications, arm **30** of tool **20** comprises one or more orientation elements **130**, which are configured to orient ultrasound transducer **40** perpendicular to atrial wall **100**, and, optionally, to position the transducer at a fixed distance from the atrial wall. The housing of ultrasound transducer **40** is configured to articulate with arm **30**. For example, this articulation may be provided by a hinge **132** that couples the housing to the arm, or by one or more springs that couple the housing to the arm (configuration not shown). For some applications, the orientation elements may be arranged generally surrounding the ultrasound transducer, e.g., shaped like one or more petals of a flower. For some applications, the elements comprise a metal, e.g., Nitinol.

Reference is made to FIG. **2**J. For some applications, ultrasound transducer **40** comprises an array **140** of ultrasound elements, such as a linear array. Array **140** enables the ablation of a line, in addition to a circular lesion around the pulmonary veins. Alternatively, the line may be ablated by moving a single transducer linearly. Alternatively or additionally, a one- or two-dimensional array is used for beam forming and/or beam stirring.

FIGS. **3**A-C are schematic cross-sectional views of the atria showing operation of ultrasound ablation system **10** for application of energy, in accordance with some applications of the present invention. For some applications, system **10** is used for the treatment of atrial fibrillation. For such applications, system **10** is used to generate enhanced ablation in areas of pulmonary vein ostia in a left atrium **110**, in order to electrically isolate pulmonary veins **80** from the rest of the heart. Enhanced ablation and scarring is achieved by creating a reflective region in the vicinity of the tissue designated for ablation, such that ablating ultrasound waves are reflected back from the reflective region and pass again through the ablation site.

As shown in FIG. **3**A, reflection-facilitation element **12** is used to provide an extramyocardial reflective region **112**, typically within pericardium **70** or between the pericardium and the myocardium. Typically, reflection-facilitation element **12** is transthoracically delivered using percutaneous subxiphoid access to the epicardium. For some applications, reflection-facilitation element **12** may comprise gas-delivery element **90**, as described hereinabove with reference to FIGS. **2**C-F, which is used to inflate pericardium **70** with gas to create reflective region **112** which reflects the applied ultrasound waves. Alternatively, the reflection-facilitation element may use other techniques for providing reflective region **112**, such as those described herein, e.g., with reference to FIG. **2**G or **2**H.

FIG. **3**A additionally shows transcatheter advancement of tool **20** into left atrium **110**, and placement of tool **20** in a location adjacent to pulmonary vein ostia in accordance with some applications of the present invention. Tool **20** is shown in a collapsed state prior to application of energy by transducer **40**. For some applications, a transseptal approach is used to advance tool **20** to left atrium **110**, using catheter **22**, as shown in FIGS. **3**A-C. Alternatively, tool **20** may be advanced to left atrium **110** using a transapical approach, via the apex of the left ventricle and the mitral valve (approach not shown). Further alternatively, tool **20** may be advanced to left atrium **110** via the aorta, the left ventricle, and the mitral valve (approach not shown). For some applications, tool **20** is first advanced into the left atrium, and extramyocardial reflective region **112** is subsequently provided, while for other applications, region **112** is first provided.

FIG. **3**B shows the opening of tool **20** into an operative state within a left atrium of the heart. Tool **20** is located adjacent to a pulmonary vein ostium, and to tissue of atrial wall **100**. Hinge **44** typically facilitates deflection of arm **30**, such that arm **30** is deflected laterally from a position that is aligned with a longitudinal axis of tool **20**. Deflection of arm **30**

brings ultrasound transducer **40** into the proximity of cardiac tissue designated for ablation treatment, such that ultrasound transducer **40** is aimed at the designated site.

For some applications, as mentioned above, distal portion **32** of tool **20** is telescopically extended into the pulmonary vein, such that anchoring element **48** (e.g., inflatable element **50**) is disposed within a lumen of pulmonary vein **50**. Anchoring element **48** is shown comprising inflatable element **50**, which is shown inflated, applying pressure to a wall of the pulmonary vein, in order to stabilize and maintain tool **20** in place during application of treatment energy. Alternatively, anchoring is not provided, or other anchoring techniques are used, such as described herein. An exploded view of ultrasound transducer **40** shows the initiation of treatment by applying ablating ultrasound waves to the tissue of atrial wall **100**.

FIG. **3**C shows the rotation of arm **30** to successively aim ultrasound transducer **40** at a plurality of sites on atrial wall **100**, typically to form a complete circular lesion **114**, thereby electrically isolating pulmonary vein **80** from left atrium **110**.

It is to be noted that system **10** can be used to treat other types of cardiac arrhythmia such as ventricular tachycardia. For such applications, tool **20** is advanced into a ventricle of a subject and lesions are created by ablation of tissue in the ventricle by application of ultrasound energy in accordance with applications of the present invention.

Reference is again made to FIGS. **1**A-**3**C. For some applications ultrasound transducer **40** is configured to transmit ultrasound energy that is capable of damaging tissue by a variety of mechanisms, e.g., ablation and/or cavitation and/or standing waves or a combination thereof.

For some applications, the ultrasound HIFU energy application techniques described herein are practiced in combination with other types of ablation, such as cryoablation and/or radiofrequency (RF) ablation.

It is also to be noted that application of treatment energy to sites within a chamber of the heart is not limited to blood vessel orifices but may be applied to any region in the heart which is involved in triggering or maintaining cardiac arrhythmias.

Reference is still made to FIGS. **1**A-**3**C. For some applications, transducer **40** comprises phased array ultrasound probes which typically transmit ablating energy in a series of rings. For such applications, transducer **40** simultaneously ablates a 360-degree circumferential lesion surrounding the orifice of a blood vessel, substantially without rotation of the transducer.

For some applications, a configuration of transducer **40** allows ablating a lesion in tissue of the subject, which is less than 360 degrees, substantially without rotating the transducer. The lesion is typically at least 10 degrees, e.g., at least 90 degrees or at least 180 degrees, and/or the lesion is less than 300 degrees, e.g., less than 270 degrees. For some applications, this less-than-360 degree ablation is performed one or both of the left pulmonary veins, in order to avoid any potential damage to the mitral valve.

Reference is again made to FIGS. **1**A-**3**C. Phrenic nerve damage is an undesired yet potential complication of catheter-based ablation procedures including ablation by ultrasound energy, as described in Sacher et al. (2007) (referenced above). Some applications of the present invention reduce the potential of damage to the phrenic nerve, e.g., to the left phrenic nerve, which is located in proximity to the left atrial appendage. Typically, for applications in which reflection-facilitation element **12** delivers gas to inflate the pericardium, the gas typically distances the phrenic nerve from the site of ablation and creates a gas-filled barrier between the phrenic nerve and the ablation site, thereby protecting the phrenic nerve from potential damage by the applied ultrasound energy.

Additionally or alternatively, some applications of the present invention reduce potential damage to the esophagus that may be caused by ablation procedures performed on the heart. Typically, for applications in which reflection-facilitation element **12** delivers gas to inflate the pericardium, the gas creates a gas-filled barrier between the esophagus and the ablation site, thereby protecting the esophagus from potential damage by the applied ultrasound energy.

For some applications, system **10** is configured to continuously or periodically monitor the treated tissue during treatment, in order to assess whether the ablation is sufficient. For some applications, the system performs the monitoring by electrical mapping of the tissue, such that conductance of electrical signals is mapped and the need for further treatment is assessed. For some applications, a multi-electrode catheter for mapping of conductance following application of treatment is used.

For some applications, system **10** monitors the treated tissue using ultrasound, typically to detect the temperature of the treated tissue. Various ultrasound parameters are dependent on the temperature of the tissue. For example, the speed of sound is dependent on the temperature of the tissue. In the case of a muscle (or atrial wall), the speed of sound increases as the temperature is elevated. Thus the time of flight (TOF) decreases as the temperature is elevated, assuming that the distance that the sound waves travel is fixed. The beating heart is more complicated, since due to atrial contraction the distance changes (even if the transducer is fixed in the same position or distance from the atrial wall). However, the distance change is predictable, and thus, for some applications, is used to extract the temperature change, as described below. For some applications, the ultrasound parameter is selected from the group consisting of: an amplitude of the ultrasound energy applied by the ultrasound transducer and reflected by the reflective region, a scatter intensity of the reflected ultrasound energy, sub-harmonics of the reflected ultrasound energy, second and higher harmonic reflections of the reflected ultrasound energy, an attenuation of the reflected ultrasound energy, and a non-linear parameter of the reflected ultrasound energy.

Additionally or alternatively, system **10** monitors ablation of the tissue using ultrasound. As described hereinabove, for some applications, the ultrasound transducer is rotated slowly while continuously transmitting ablating ultrasound energy, thus creating a continuous circular lesion surrounding the orifice of blood vessel. As provided by some applications of the present invention, following ablation of the tissue, the ultrasound transducer is activated to apply low intensity ultrasound energy to the ablated tissue such that at least a portion of the transmitted energy is reflected by the tissue onto the ultrasound transducer. System **10** typically comprises a processor configured to monitor a pattern of the reflected energy (echo) received by transducer **40**. If the circular lesion is continuous, the echo pattern shows a continuous pattern with generally steady intensity. If the circular lesion is not continuous and gaps appear in the ablated tissue, the echo pattern presents varying intensities. For some applications, further energy application to the tissue is applied following monitoring of the treated tissue and assessment of the tissue ablation. For such applications, additional "touch up" treatment may be applied by any suitable ablation-generating method e.g., ultrasound (e.g., HIFU or low intensity focused or non-focused ultrasound) and/or by RF energy, and/or by cryoablation.

FIGS. **4**A-B are graphs showing changing parameters in cardiac tissue resulting from heating of the tissue as determined by simulated ultrasound monitoring, in accordance with an application of the present invention (all units are arbitrary units (AU)). For some applications, ultrasound is used to monitor the treatment. For these applications, waves reflected by a reflective region in the tissue, e.g., a gas between the pericardium and atrial wall, are detected by ultrasound transducer **40**, and the time of flight (TOF) is then measured. Changes in the time of flight (TOF) can be used as an indicator for proper heating of the tissue, in accordance with some applications of the present invention.

The graph in FIG. **4**A shows a dashed line representing time of flight (TOF) in cardiac tissue under normal, untreated conditions. The TOF exhibits generally sinusoidal behavior due to contractions of the atrium. As described above, as a result of heating of a muscle, e.g., cardiac muscle, the speed of sound in the muscle typically increases. The continuous line in FIG. **4**A represents (simulated) TOF in muscle tissue that has been heated by ultrasound energy applied thereto. The changes in TOF enable ultrasound monitoring of the treatment applied, in accordance with applications of the present invention.

The graph in FIG. **4**B shows the result of signal processing of the TOF parameter, in accordance with an application of the present invention. The processing includes generating an average moving window having a width equal to a period of the beating heart (i.e., the heart rate). The dashed line shows a case with no heating, and the solid line shows a case that includes heating. Using an average moving window, the sinusoidal behavior is eliminated and the inclination of the TOF is obtained, thus monitoring the temperature of the ablation.

When the monitored temperature shows that the target temperature has been obtained, the ultrasound transmission is ceased, and the transducer is rotated to a different radial location, either manually by the physician, or by a motor, e.g., driven by a control unit of system **10**.

For some applications, system **10** alternatively or additionally measures other ultrasound parameters, such as the amplitude of reflected ultrasound waves, scatter intensity, subharmonics, second and higher harmonic reflections, attenuation and/or non-linear parameters, The system uses these measured parameters as indicative of change in the treated tissue. When sufficient change is obtained, the ultrasound transmission is ceased and the transducer rotated, either manually by the physician, or by a motor, e.g., driven by a control unit of system **10**.

It is noted that inflatable element **50**, the telescopic expansion of distal portion **32** of tool **20**, arm **30**, and the 360 rotation of tool **20** are described hereinabove by way of illustration and not limitation, and the scope of the present invention includes a system that includes only some, or none, of these elements.

Reference is now made to FIG. **5**, which is a schematic illustration of an alternative configuration of system **10**, in accordance with an application of the present invention. In this configuration, ablation tool **20** is configured to apply ultrasound energy to a series of areas on the heart wall from a location outside of the heart, such as against or near an outer surface of the pericardium. Reflection-facilitation element **12** is configured to be placed inside the left atrium, to provide the reflective region within the atrium. For example, the reflection-facilitation element may comprise an inflatable element **150**, such as described hereinabove with reference to **2**H, mutatis mutandis, or a shaped acoustic reflector, such as described hereinabove with reference to **2**G, mutatis mutandis. Optionally, the inflatable element is shaped so as to define a passage therethrough to allow the flow of blood. For some applications, reflection-facilitation element **12** is placed inside a ventricle of the heart for treatment of cardiac arrhythmias originating in the ventricle.

For some applications as described hereinabove, the ultrasound energy is applied to treat cardiac arrhythmias, such as ventricular fibrillation; and/or ventricular tachycardia. For such applications, the ultrasound energy is directed towards myocardial tissue sites (e.g., the interventricular septum) which are involved in triggering, maintaining, or propagating these ventricular cardiac arrhythmias.

For example, for some applications (not shown) in order to create a lesion in the interventricular septum, a reflection-facilitation element comprising an inflatable element (e.g., a balloon) is inserted into a ventricle of the subject. The inflatable element is typically inflated with a fluid having a lower density than water, such as a gas (e.g., carbon dioxide). It is noted that in this context in the specification and in the claims, the term "fluid" includes gases and liquids. The low-density fluid functions as the reflective region described hereinabove. An ultrasound transducer is typically placed in the opposite ventricle, and ultrasound energy that is transmitted by the transducer towards tissue of the interventricular septum is reflected due to the fluid-filled (e.g., gas-filled) balloon, such that the return energy waves pass again through the tissue. Similarly, inserting the fluid-filled (e.g., gas-filled) balloon into a ventricle may be used to reflect the ultrasound energy on to any region of tissue of the opposite ventricle, for creating a lesion in the tissue in accordance with some applications of the present invention.

Reference is now made to FIGS. **6**A-D. For some applications, system **10** is configured to allow a physician to provide a reflective region at a far side of tissue of a subject and to assess whether the reflective region is in a desired location, by means of acoustic sensing, and in response, to apply ablating energy to the tissue. For some applications, system **10** is configured to transmit low intensity, non-ablating ultrasound energy in order to verify proper positioning of reflection-facilitation element **12**. Typically, reflection-facilitation element **12** comprises gas-delivery element **90**, which is advanced, e.g., transthoracically, towards an extramyocardial site of a subject. System **10** is configured to monitor advancement of gas-delivery element **90** and verify proper positioning within the extramyocardial site, specifically within a desired pericardial region as described herein. Ultrasound transducer **40** is activated to continuously apply non-ablating low intensity ultrasound energy to myocardial tissue, while element **90** is transthoracically advanced towards the pericardial region of the subject. While being advanced, element **90** continuously or intermittently releases small amounts of a gas, in order to provide reflective regions. System **10** assesses the proper positioning of gas-delivery element **90** within the pericardial region and the providing of the reflective region by measuring the amplitude of the ultrasound echo received by transducer **40**. The amplitude of the echo is small if gas-delivery element **90** is remote from the pericardial region (because there is no gas yet in the pericardial region), and increases sharply when gas-delivery element **90** is properly positioned in the pericardial region. Typically, in response to assessing that the gas-delivery element and consequently the reflective region are in the desired location, the ultrasound transducer is activated to ablate the tissue as described hereinabove.

FIG. **6**D is a graph showing a simulated change in echo amplitude of received ultrasound waves over a time period in which the gas-delivery element is being advanced towards and subsequently into the pericardial region. As shown, the

amplitude of the echo increases sharply over the period of time which typically corresponds to penetration of the pericardial region. Additionally or alternatively, an acoustic sensing element, e.g., an ultrasound or other transducer, functions in a microphone mode, detecting the release of gas into the pericardial region.

Reference is made to FIGS. **7**A-B, which are experimental results showing histological images of cardiac tissue following application of ultrasound energy thereto, in accordance with some applications of the present invention.

Reference is first made to FIG. **7**A. In this experiment, ultrasound energy was applied to a near side of the tissue, and liquid was placed at a far side of the tissue. The ultrasound energy was applied at 4 W for the duration of 120 seconds. As shown in the histological image in FIG. **7**A, the applied energy caused 0.45 mm of patchy foci of coagulation in the tissue.

Reference is now made to FIG. **7**B. In this experiment, ultrasound energy at a similar dose as applied to the tissue in FIG. **7**A (4 W for the duration of 120 seconds) was applied to a near side of the tissue, and a gas-filled reflective surface was provided at a far side of the tissue. As shown in the histological image in FIG. **7**B, the applied energy caused full thickness (4.5 mm) necrosis in sections of the tissue, affecting myocardium tissue. The treatment energy applied by the ultrasound transducer to the sites in the myocardial tissue was reflected from the gas-filled reflective region back through the myocardial tissue, causing the enhanced damage to the tissue shown in FIG. **7**B, compared to FIG. **7**A (which utilized a liquid-filled reflective region).

Reference is made to FIGS. **1**A-**3**C and **5**-**6**D. For some applications, separate ultrasound transducers are utilized for delivery of non-ablating and ablating energy. For example, a focusing ultrasound transducer may be used for delivery of ablating energy. Additionally or alternatively, flat ultrasound transducers and/or diverging ultrasound transducers that spread ultrasound waves and typically sense a larger area may be used for delivery of non-ablating energy.

Reference is again made FIGS. **1**A-**3**C and **5**-**6**D. For some applications, reflection-facilitation element **12** comprises electrodes that create gas in order to provide a reflective region.

It is noted that for some applications the use of a gas-filled region as described herein is used in combination with other ablation techniques for example, cryoablation and/or radiofrequency (RF) ablation. Typically, the use of the gas-filled region improves efficacy of the ablation treatment as well as enhancing safety. The gas-filled region typically isolates the treated area such that cryoablation treatment is improved. Additionally or alternatively, the gas-filled region typically improves electrical conductivity improving the effects of RF treatment.

Although techniques of the present invention have generally been described herein as being applied to cardiac tissue, these techniques may additionally be used, mutatis mutandis, to treat other tissue of a subject, such as liver tumors or varicose veins or nervous tissue. For some applications, these techniques may additionally be used, mutatis mutandis, to treat other tissue of the subject e.g., a uterus and or one or more locations along the gastrointestinal tract. For some applications these techniques may additionally be used, mutatis mutandis, to treat prostate tissue of the subject, e.g., by inserting the ultrasound transducer through the urethra and providing a reflective region in the rectum, e.g., by inflating the rectum or positioning a gas-filled balloon in the rectum. For some applications, these techniques may additionally be used, mutatis mutandis, to treat the lungs and lung vasculature. For such applications, a gas present in lung of the subject typically provides a reflective region for enhancing application of treatment energy to adjacent tissue.

The techniques described herein are used to provide a reflective region at a far side of the tissue, by placing a reflective-facilitation element at the far side, and to ablate the tissue by applying ultrasound energy to a near side of the tissue such that at least a portion of the applied energy is reflected onto the tissue by the reflective region. Additionally or alternatively, these techniques may be used to monitor a tissue of a subject by providing a reflective region at a far side of the tissue, by placing a reflective-facilitation element at the far side and applying non-ablating ultrasound energy to a near side of the tissue, such that at least a portion of the applied energy is reflected onto the tissue by the reflective region. It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

The invention claimed is:

1. A method comprising:

providing a reflective region at a far side of a tissue wall of a subject, the tissue wall having the far side and having a near side; and

ablating the tissue wall by applying ultrasound energy to the near side of the tissue wall such that at least a portion of the applied energy is reflected onto the tissue wall by the reflective region,

wherein the tissue wall includes tissue of a subject selected from the group consisting of: nervous tissue, uterine tissue, prostate tissue, lung tissue, and tissue of the gastrointestinal tract, and

wherein ablating the tissue wall comprises ablating the selected tissue.

2. The method according to claim **1**, wherein providing the reflective region comprises placing a reflective-facilitation element at the far side of the tissue wall, and using the reflective-facilitation element to provide the reflective region.

3. The method according to claim **1**, wherein providing the reflective region comprises providing a gas at the far side.

4. The method according to claim **1**, wherein the selected tissue includes the nervous tissue and ablating the tissue wall comprises ablating the nervous tissue.

5. The method according to claim **1**, wherein the selected tissue includes the uterine tissue and ablating the tissue wall comprises ablating the uterine tissue.

6. The method according to claim **1**, wherein the selected tissue includes the prostate tissue and ablating the tissue wall comprises ablating the prostate tissue.

7. The method according to claim **1**, wherein the selected tissue includes the lung tissue and ablating the tissue wall comprises ablating the lung tissue.

8. The method according to claim **1**, wherein the selected tissue includes the tissue of the gastrointestinal tract and ablating the tissue wall comprises ablating the tissue of the gastrointestinal tract.

* * * * *